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Tonopah Mining District.

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[The Tonopah mining district is one of the fresh discoveries of rich ores of gold and silver in the west. The geology of the region is extremely complicated and there are many features of especial scientific and practical interest. In very few mining districts is the discovery and proper development of the ores so dependent upon a knowledge of the principles of economic geology. The author of this paper has spent the larger part of several years studying the district, and some of the most interesting results are outlined below.—THE EDITOR.]

The mining district of Tonopah, in Western Nevada, has attracted much attention among mining men during the last few years, on account of the considerable quantity and rich character of its gold-silver ores. This district lies in an arid region, which, although formerly considerably explored and exploited by miners, had, for a long time previous to the discovery of

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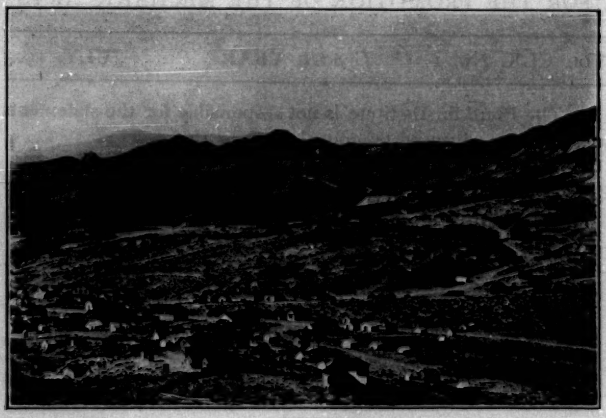
this camp, been practically abandoned. Within this same region lie the famous camps of Virginia City and Eureka, which twenty or thirty years ago were very heavy producers, but which have gradually dwindled more and more in importance. Numerous other camps were, in those old ways, scattered thoughout this desert country, such as Silver Peak, Hot Creek, Tybo, Reveille, Candelaria, and many others, but most of these had become nearly or quite deserted.

A preliminary event which is directly responsible for the discovery of Tonopah was the location of a small camp, called



Tonopah.

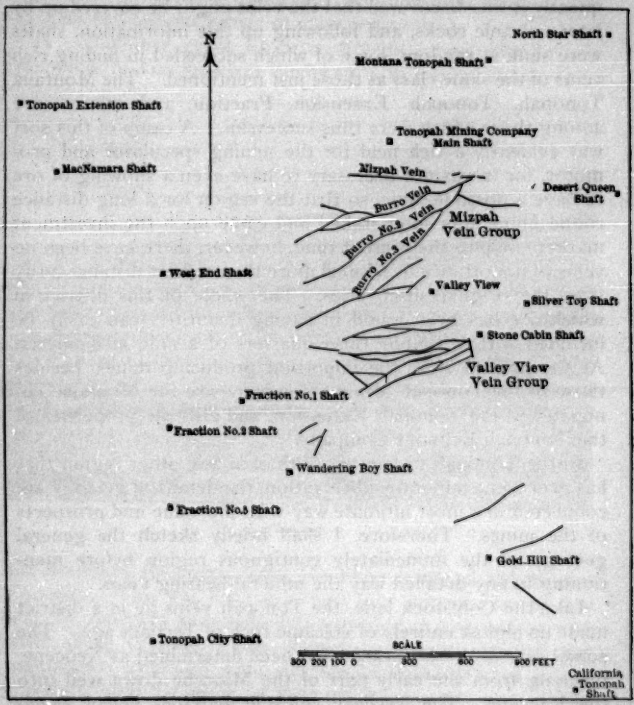
the Southern Klondike, some ten miles south of the present Tonopah. This was located a short time previous to my first trip, by ranchers who visited the locality in connection with their sheep herding. This district has never attained any importance, although some ore has been taken from it. In traveling from his home, in Belmont, the county seat of Nye County, to the Klondike camp, James L. Butler collected specimens from the veins outcropping on what is now called Mizpah Hill, at Tonopah, and thus led to the discovery of this now famous camp. The properties that Mr. Butler located

were at first worked by him on the leasing system, and afterwards disposed of to the Tonopah Mining Company, the stock of which is chiefly held in Philadelphia. The group owned by this company on Mizpah Hill comprises the Mizpah and Valley View veins, which are the chief outcropping lodes. Subsequently it was discovered that the veins might be covered up by later volcanic rocks, and following up this information, shafts were sunk at random, some of which succeeded in finding rich veins of the same class as those just mentioned. The Montana Tonopah, Tonopah Extension, Fraction, and others, are among those which were thus successful. A camp of this sort was evidently a rich field for the mining speculator and promotor, for it was not necessary to have even a showing of ore to have a possible mine, so that the region for a long distance round about was soon staked and came upon the investment market. Up to the present time, however, there have been no veins of importance developed more than a short distance away from the original discoveries. The whole of this district in which ore has been found in paying quantities can easily be included within a circle three-quarters of a mile in diameter. At the present time the important producing mines, besides those of the Tonopah Mining Company, are the Montana Tonopah and the Tonopah Extension, and also the properties of the Tonopah Belmont Company.

In the Tonopah district more than in any other region that has ever come under my observation, the details of geology are connected in a most intimate way with the value and prospects of the mines. Therefore, I shall briefly sketch the general geology of the immediately contiguous region before mentioning in any detailed way the mineral-bearing veins.

Like the Comstock lode, the Tonopah veins lie in a district made up almost entirely of volcanic rock of Tertiary age. The actual date of these volcanics has been determined as Neocene, reaching from the early part of the Miocene down well into the Pliocene. The Tertiary volcanic activities began somewhat before the earliest period mentioned and continued after the latest manifestation which we have at Tonopah. At the neighboring camp of Silver Peak, sixty miles west of Tonopah, there is a basalt crater which can hardly be more than a few hundred years old.

The earliest of the volcanics at Tonopah, and the one with which the principal ore deposits are most closely connected, was an andesite, which I have called the earlier andesite, to distinguish it from a subsequent erupted rock of very nearly simi-

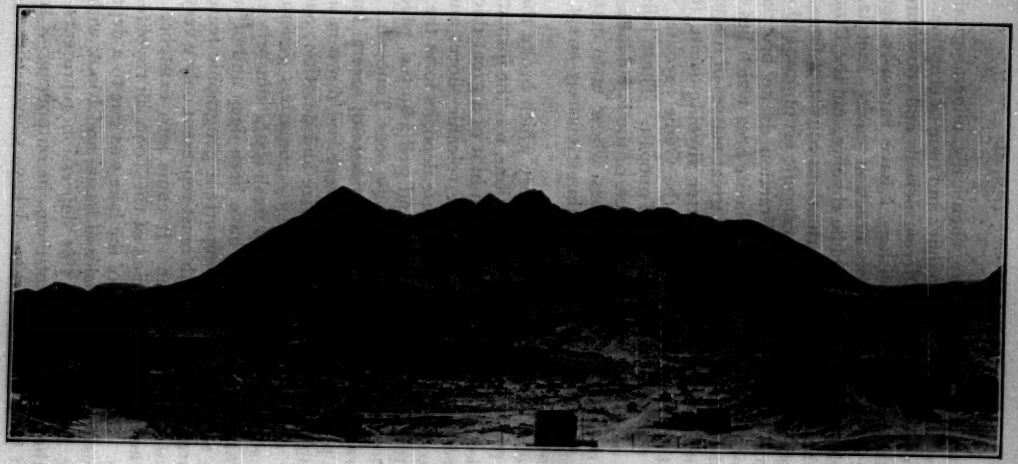


Map showing outcropping veins at Tonopah

lar composition. In the camp it is often called the lode prophyry, since in it the most valuable veins lie. The later andesite succeeded the earlier andesite after an interval. Subsequently the continuation of the volcanic activity is attested by a series of rhyolites and dacites. These rocks are very

closely connected in every way, chemically, mineralogically, in point of distribution, and in manner and time of eruption. They were, however, erupted at different periods and constitute distinct formations. These divisions I have variously denominated the Heller dacite, the Fraction dacite breccia, the Tonopah rhyolite-dacite, the Oddie rhyolite, and the Brougher dacite. These rhyolite-dacite formations consist of flows, tuffs due to showers of material from volcanic eruptions, and of injections into older rocks. The Fraction dacite breccia and that part of the Tonopah rhyolite-dacite area which lies south of Tonopah, in particular, consist of great masses of fragmental volcanic material. Among the latter rhyolite-dacite formations are the Brougher dacite and the Oddie rhyolite, which constitute the isolated hills around Tonopah. These hills represent the necks of Tertiary volcanoes, or the liquid lava which cooled in the throats of the volcanoes, whose main mass was made up of cinders and ash, now almost entirely swept away by erosion.

An incident in the geological history which broke the monotony of the repeated volcanic eruptions, was the formation of a great lake basin, and the deposition in it of a great thickness of stratified materials worn from the volcanic shores and carried out to settle in its depths. These deposits form the white stratified tuffs, beautifully bedded and well assorted, which are a conspicuous feature of the geology near Tonopah. Since these characteristics persist for thicknesses of several hundred feet, it is plain that the sediments were laid down in a body of standing water of considerable size and duration; and that this body was a lake is indicated by numerous general considerations and by the presence of fresh water infusoria in some of the strata. This lake must have been deep and of such an extent as to make it a very important geographic feature, so that the area around Tonopah must represent only a very small fraction of its whole extent. It came into existence at the close of the most active period of the Tonopah rhyolite-dacite eruptions. The formation of the lake was due to a depression of the crust, forming an enclosed basin, and I look with favor upon the hypothesis that this depression represents a collapse of the crust consequent upon the outpouring of so great a bulk of lava, gas and steam. I have proved that a similar



Mount Butler. A denuded volcanic neck.

subsidence, due beyond question to this cause, followed upon the eruption of the dacite and rhyolite volcanoes which are now represented by the volcanic necks already referred to. This lake basin, in this area at least, was terminated by an uplift of the crust, accompanied by a regional tilting. The area remained for a short time a quiet land surface, but soon there was an explosive eruption of basalt, followed by a thin flow of the same material. The formation of the dacite volcanoes, represented by the present hills, followed almost immediately upon this basaltic eruption. In connection with this last dacitic outburst there was a phenomenon of great importance, both to the scientist and to the miner, namely the faulting. I have shown that the principal faulting followed directly upon the formation of these dacitic cones. I have also shown that the area occupied by this dacite, which I have called the Brougher dacite, is coextensive with the region of observed complicated faulting. This complexly faulted region, which makes up the southern half of the small area which I have mapped,* is also down-sunken in comparison with the little-faulted region further north. Near the dacite necks the observed faults are rather more numerous than elsewhere, and in many instances it may be established that the blocks adjacent in the dacite have sunk down in reference to blocks farther away. From these intrusive necks the faults run in a roughly radial fashion, and seem to follow no regular system or trend. Detailed study of the contact phenomena of the dacite shows that the minute faults in the tuffs at these points generally have their downthrown side next the dacite.

From these facts I have reached the following conclusions. The faulting was chiefly initiated by the intrusion of the massive dacite necks. After this intrusion and subsequent eruption there was a collapse and sinking of the various vents. The still viscous lava sank, dragging downward with it the adjacent blocks of the intruded rock, accentuating the faults, and causing the described phenomena of downfaulting in the vicinity of the dacite.

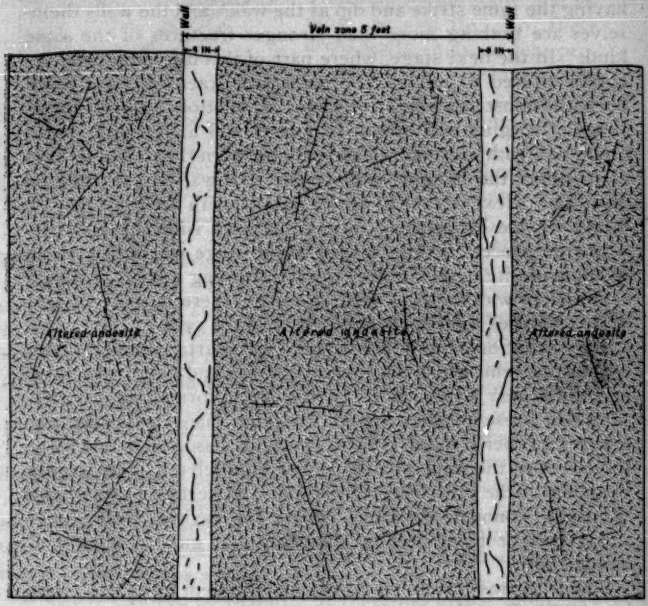
The observations made upon faulting in this district are of extraordinary interest, for in this case the origin, time and

*Professional Paper No. 42, U. S. Geological Survey.

cause of the faulting are clearly understood. It is rare that any explanation other than a general unsubstantiated hypothesis can be applied to any particular case of faulting, but here it is plain that the faulting was the result of adjustments of the crust to suit violent migration of volcanic rock, that it originated with the swelling up of the crust and its forcible thrusting up and aside to make way for the numerous columns of escaping lava, and that it was continued after the cessation of the eruptions by the irregular sinking of the crust into the unsolid deposits from which the lava had been ejected. It can readily be seen that all sorts of pressure—from below upward, lateral, and downward by virtue of gravity,—must have been concerned in such movements; moreover, that the first faults were due rather to upward and lateral irregular shoves, while the latter ones, in many cases along the same planes as the first, were due to gravity. Thus reversed or normal faults are equally natural and both occur frequently. I will refer in detail later on to some special cases of faulting, after having described the mineral veins.

The veins in the earlier andesite at Tonopah have the regular extent, strike and dip characteristic of true veins. I have found out, however, by studying them, that they are not the fillings of open cavities, but rather that they have formed along zones, of maximum sheeting, these zones being from 3 to 8 feet wide, and having a regular strike and dip. For this reason I have announced that the veins were not true fissure veins, but were chiefly due to replacement. It is only fair to state, however, that the definition of a fissure vein is not universally agreed upon, so that veins having the origin which I have described would still be called fissure veins by some prominent geologists. Personally, I limit the term to veins which have filled open fissures, but by some the term is extended to any vein which is formed along what they denominate a fractured or fissured zone, even if it has formed by replacement of the rocks of this zone. The chief set of fractures along which the veins were formed extended in an east and west direction, and along zones which attain the maximum thickness of several feet, the close-set parallel fractures were especially abundant. These became the chief channels of circulation. In places the circulating waters divided into sepa-

rate channels, which diverged and frequently re-united, and often a lateral channel was found, of a character favorable to the egress of the water. Along these branch veins were formed. These channels, however, were apt to grow poorer as the distance from the main fracture zone increased, and these characteristics have been inherited by the veins which formed along them. The circulation channel now occupied by the Mizpah



Detailed vertical section of one of minor Valley View veins at surface.

vein may be taken as typical of the main fracture zone, and the diverging Burro veins, dwindling as they increase their distance from the master vein, as representing the lateral channels. The splitting and re-uniting is shown by the structure of the veins at many points.

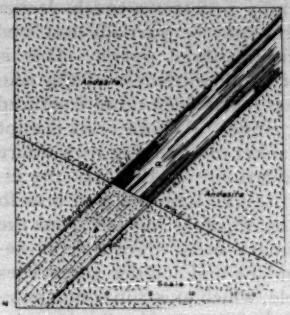
The fact that the circulation channel was a fracture zone and

not an open fissure is shown by a study of the veins, revealing all stages in the change from a fracture zone in andesite to a solid quartz vein. In many cases the vein consists simply of a zone of more or less altered andesite, not essentially different, except for a somewhat greater silicification, from the andesite which forms the walls. This zone is cut by parallel fractures having the same strike and dip as the walls, and the walls themselves are nothing more than stronger fractures of the same kind. In the next stage, where part of this fractured zone becomes altered to quartz, the main wall fractures have often been the most favorable for water circulation, so that sometimes a hanging-wall streak of quartz and a foot-wall streak are found, with only altered andesite between them. Sometimes also, either the hanging-wall or the foot-wall streak may be wanting. Next streaks of quartz parallel with the walls may be found, or the quartz may form a network with the andesite. Thus the process may be traced to the stage where the whole of the andesite is replaced by quartz, forming a solid vein several feet in width. As a rule, however, there is more or less of decomposed andesite forming part of the vein.

As exceptions there are streaks of quartz, usually small, within the vein, which show crustification and comb structure, and thus bear evidence of having been formed in cavities. Many of these cavities are of irregular shape and were not fissures, properly speaking, but spaces of dissolution, and were the effect of the mineralizing waters themselves. The largest examble of the crustified vein is found in certain parts of the Montana Tonopah workings, where the cavities were sometimes two or three feet in diameter and gave rise to well banded ore.

The fractures transverse to the main system have also a not inconsiderable effect in determining the course of the ore-bearing solutions. Along important transverse fractures I have found that the vein narrows, the cross fractures playing the same part as the lateral wall fractures, even if not always to such an extent, and so earning the name which I have given them, of *cross walls*. I am not aware that this feature of cross walls in vein structure has ever before been recognized, but it is a conception that is extremely important to the miner. It can readily be seen that once the conception of the

main vein as due to the effect of maximum circulation along an especially fractured zone is understood, the effect of strong cross fractures in limiting or even locally cutting off the circulation from some portions of the vein zone becomes clear and even follows naturally and almost necessarily. To these cross walls, more or less pronounced, the division of the water circulation along the main zone into columns of unequal importance was due, and hence the mineralization accomplished by these waters was correspondingly localized. It is probable that the recognized ore shoots or bonanzas had their origin in this way.



Cross-wall in Montana Tonopah vein. a—rich ore, b—low-grade vein stuff.

The primary ores, where practically unaffected by oxidation, as in the Montana Tonopah and Tonopah Extension mines, consist mainly of solid sulphides. The gangue of these veins is chiefly fine-grained quartz, with a great deal of potash feldspar, adularia, a pure variety of orthoclase. Sericite, the fine variety of muscovite, is also frequently present, and sometimes also a mixed carbonate of lime, iron, magnesia and manganese. The principal metallic mineral of the ores is argentite, and there is considerable polybasite and probable stephenite, often in characteristic crystals. Chalcopyrite and pyrite also occur, with some galena and probably some blende, although the latter mineral has not been detected in the hand specimen. Gold is present in the average ore in the proportion of gold to silver equals 1 to 100 by weight. It therefore makes up about two-fifths of the ore values,—the silver three-fifths. In the sulphide ores it has never been detected by the eye, whether in the hand specimen or under the microscope, although it has been found in metallic particles under both these circumstances in the partially oxidized ore. An analysis of the sulphide ores by Dr. W. F. Hillebrand shows about 2½% of selenium, part of which at least exists as a silver selenide.

There is no tellurium so far as yet determined. The veins

have been oxidized in part from the surface downward, but owing to the fact that there is no regular groundwater, the oxidation has been partial, extending very irregularly downward. Along veins the oxidation generally penetrates much deeper than in the rock, so that the ores may be partially oxidized while the country rock contains unaltered pyrite. This is plainly due to the greater rigidity and brittleness of the vein as compared with the rock, so that it has been more fractured by strains and affords a readier channel. Where veins do not outcrop but are covered with a blanket of overlying rock, there is usually comparatively little oxidation. In the ores the effects of oxidation are to alter pyrite into limonite, and also to deposit black oxide of manganese, which is formed from the manganese carbonate in the primary ores. Horn silver becomes abundant, and silver bromides and iodides sometimes accompany the chloride. The gold, which exists in some undetected combination in the sulphide ores, is largely deposited as metallic particles in the oxidized zone. Analyses of the typical ore of the oxidized zone, such as that in Mizpah vein, shows that it still contains a large amount of argentite. No important change in the amount of gold and silver, as compared with the unoxidized ores, has been proved. It is thus seen that the so-called oxidized ore of the Tonopah district, like that of many other deposits of desert regions, is really a modified ore, consisting of an intimate mixture of original sulphides and selenides, together with secondary sulphides, chlorides and oxides.

In both the oxidized and unoxidized zone secondary sulphides are frequent. These are chiefly pyrargyrite and argentite, and occur coating cavities which cut the primary ore. They are of later deposition than the primary ore, and are probably due to descending waters. They have not, however, so far as detected, caused any important readjustment in the values of the different zones.

In studying this mining district I have compared it with certain others which are closely similar to it. Probably the nearest analogies yet described anywhere in the world are the contiguous mining districts of Pachuca and Real del Monte, in Mexico. These are among the most important districts in Mexico, and have produced enormous quantities of ore. They

are situated in a range made up of Tertiary andesites, rhyolites and basalts. The veins are argentiferous with an appreciable amount of gold. They represent in a vertical sense two zones, the upper composed of oxides (red ores) and the lower of sulphides (black ores). The first, which has a downward extent of nearly 1,000 feet, contains chlorides and bromides of silver; the lower zone contains sulphides of lead, silver, etc. The lower limit of the upper zone corresponds to the groundwater level. The ore occurs in rich masses, called bonanzas, which are of irregular form. The impoverishment of the veins at great depth is admitted.

Besides these districts there are many others in Mexico which have been described as having very nearly the same characteristics. They occur chiefly in andesite. Senor Aguilera, Director of the Mexican Geological Survey, remarks in an article on the ore deposits of his country:—"It would be tiresome to enumerate all the silver veins of Mexico which occur in andesite, but it has been said that the majority of the silver veins are in various species of this rock, which Humboldt designated as metalliferous porphyries."

The Comstock lode, which lies nearly 150 miles northwest of Tonopah, presents also a very close analogy to it. The lode is formed along a fault line in Tertiary eruptive rocks, chiefly andesites. The lode material is quartz, certain limited portions of which contain large quantities of silver and gold, and so constitute bonanzas, while the rest is low grade. Most of the bullion has been derived from a black quartz like that of Tonopah, the color being mainly due to disseminated argentite, which is the principal ore mineral and which is accompanied by gold, probably free. Bunches of stephenite, polybasite and ruby silver were also found. In the bonanzas near the surface chlorides and native silver occurred. Frequently the ore grew base and carried quantities of galena, zinc-blende, etc.

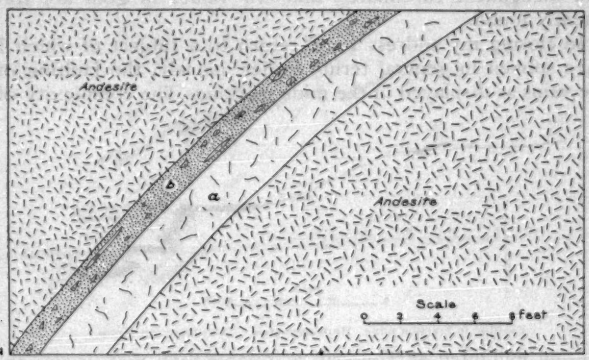
From these and other instances it appears that ore bodies of the Tonopah type occur repeatedly in the Tertiary volcanic rocks, especially in the andesites. In this connection it is interesting to consider the relation of the lavas in which the ores occur. The lavas of the Great Basin region of Nevada were studied by myself in 1900, and this study led to the conclusion that the whole region southward into the Mojava

desert, together with a portion, at least, of the Sierra Nevada, constitutes a petrographic province; that is to say, it is underlain by a single body of molten magma, which has supplied at different periods lavas of similar composition to the different parts of the overlying surface. The limits of this sub-crustal basin are not yet defined. Subsequently the studies of the Mexican geologist Ordonez extended this petrographic province into Mexico; and it is also probable that it extends a long distance northwest of Nevada.

In a paper published by myself in the Transactions of the American Institute of Mining Engineers I have subsequently brought forward the idea of a metallographic province, characterized by the presence of certain metals, and pointed out that these provinces may or may not be closely identified with petrographic provinces, though they probably are to a certain extent. Unquestionably the close relation between the Nevada mineral districts of Tonopah and the Comstock, with the far more numerous array in Mexico, and the individuality of this group as compared with other known veins of the world show a metallographic province which in this case coincides with a portion of the petrographic province previously mentioned. It is probable that the coextension of the metallographic and the petrographic province is greater than thus established. For at many other points along the belt of the petrographic province, in the Andes of South America, and elsewhere, veins are reported having, so far as can be made out, a similar mode of occurrence, age, and composition as those of Mexico. In general the Miocene andesites of this region are, as Humboldt noted, the metalliferous formation *par excellence*. And if the conclusions arrived at in the case of Tonopah are correct, the ore is due to the after actions of the eruptions, in the shape of fumaroles, solfataras and hot springs.

Besides the earlier andesites, some of the other volcanic eruptions of the Tonopah district were followed by ascending hot waters, which produced veins carrying some values in gold and silver. None of these, however, are comparable in size and importance to the veins of the earlier andesite. The chief of these lesser periods followed upon the eruption of the rock called the Tonopah rhyolite-dacite. On account of their resemblance of the earlier andesitic veins, these later rhyolitic

veins have been the object of recent exploration and development work, which on the average has been decidedly unprofitable. These veins are characterized by irregularity and a lack of definition and persistence, though their size may locally be great. The nature of the quartz is as a rule dense and jaspery, the color being white, gray or black. It is, therefore, usually of a different appearance from the white quartz of the early andesitic veins. The rhyolitic veins are usually barren, or contain only very small quantities of gold and silver, except locally, where rich bunches of ore occur. They are usually of irregular form and extent. A characteristic of the

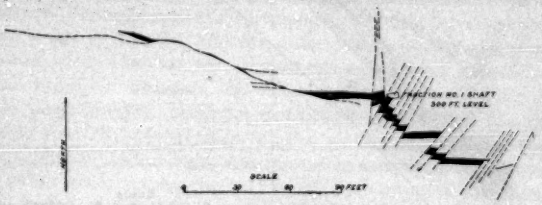


Cross-section of Tonopah extention vein, sh owing older, earlier andesite vein (a), and later filling (b) of rhyolite-docite period.

rhyolitic veins, to which there are, however, exceptions, is the greater ratio of gold to silver in them as compared to that in the earlier andesitic veins. The veins are, as a rule, confined to the rhyolite-dacite with which they are genetically connected. Yet in some places the waters must have traversed the andesite and found their way along the andesitic veins. Indeed it is along these brittle veins and the silicified adjacent andesite that fractures and fissures must have been most easily formed at this period, in the case of the Tonopah Extension an earlier andesitic vein has been reopened and along the hanging-wall a new vein of barren jaspery quartz formed. This is probably due to waters of the rhyolite-dacite period of mineralization.

The period of intrusion of the white rhyolite, which forms two of the hills near the town of Tonopah, was also accompanied by manifestations of hot spring activity. The top of Mount Ararat is composed of a volcanic plug of rhyolite. In this plug are veins which are locally as much as twenty feet thick, but are irregular and non-persistent. These veins conspicuously follow the contact and are co-terminous with it, and sometimes they cut across the rhyolite plug. They are fine examples of veins which have filled open fissures. The gangue consists mostly of brown and white calcite containing some iron and manganese carbonates, and low values in gold are frequently found.

In closing my address I will return to a subject of which I have spoken in general terms earlier, namely, the faulting of the veins as displayed in the mine workings. The complexity of

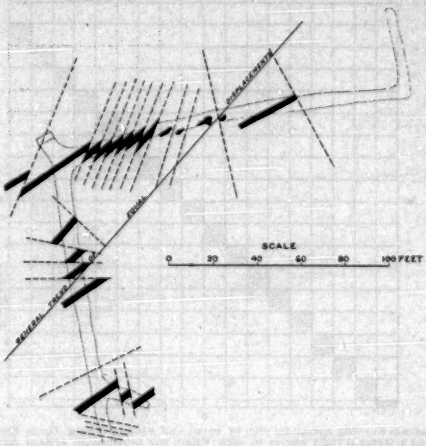


Faulting in Fraction mine. Horizontal plan. Dashed lines are faults.

faulting exhibited at Tonopah is greater than that in any reported district. It would be useless to describe all the variations of rock movement brought out by underground workings. I will briefly call attention, however, to some of the most interesting cases.

The Fraction No. 1 shaft was the first which encountered ore beneath the overlaping cap rock. Some of this ore was rich, but with development the vein was found to be so badly faulted that development has been for a long time discontinued Apparently originally there was a single vein, but it has been cut by numerous faults, which, however, may be separated into definite systems. The most important system strikes northeast and dips southeast 45°. By these faults the vein, as seen on a horizontal plane, is moved to the north on the west side. There are many of these, which disturb the faulting between

them and constitute a fault zone, whose limits and total displacement are not known. Abundant and strong striations on these fault planes, together with evidence afforded by the minute faulting and stringers and by the dragging of faulted veins, indicate that the general result was that the blocks on the west side of the separate northeast faults were shoved northward past the blocks on the east side, nearly horizontally but with a slight downward plunge. There is also a well marked system of faults striking north of west, sometimes parallel to the veins, but generally cutting across them at slight angles.



Faulting of "Wandering Boy" vein. Horizontal plan. Heavy black bands are veins. Dashed black lines are faults. Dotted lines show mine workings.

In cross section it is seen that the veins follow a series of pronounced rolls steepening and flattening alternately. In the mine it is evident that these rolls are the result of pressure and deformation in the rock, and are in the nature of folds. In the two upper levels, as shown in the cross section, at the sharp bend or apex of these folds, tangential fractures or slight faults leave the vein and pass off into the surrounding andesite. Between the 300- and 400-foot levels a flat fault striking and dipping in the same sense as the vein has probably the same

origin as the flat tangential slips in the upper levels, but is here of greater magnitude, so that the vein has actually been faulted considerably along it.

In the Wandering Boy workings also the veins are thrown into great confusion by faulting. Analysis of this disturbance leads to the conclusion that the faulting can be referred to two major systems, that of the Wandering Boy fault, which strikes northwest, and that of the Fraction fault, which strikes northeast. On the 300-foot level of the Wandering Boy the faulting

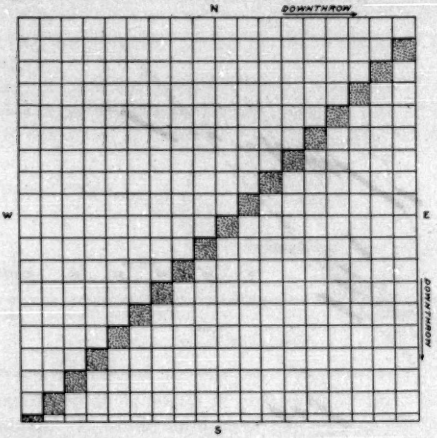
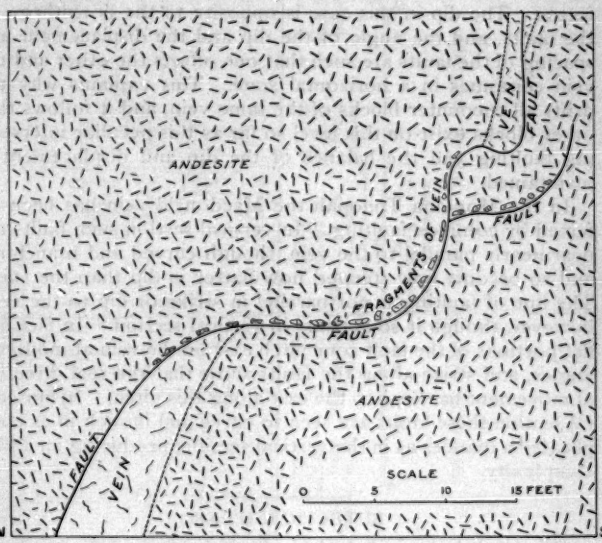


Diagram showing horizontal plan of equal and equally special faults belonging to two interesting systems at right angles to each other; the north south system having a regular downthrow on the east, and the east-west system a regular downthrow on the south side. The heavy zigzag line represents one of the lines of equal faulting; the shaded squares, one of the zones of blocks of equal displacement.

is highly interesting and complicated. The main workings consist of two drifts at right angles, one running nearly east and the other south. The vein in this level is three to four feet thick, with a northeast strike and a dip of 30° to 40° southeast. The east drift therefore runs somewhat diagonally to the strike of the vein, though more nearly along the strike, while the south also runs diagonally, though also somewhat more across the strike. Near the end of the south drift a short east drift has been run. In all these drifts the vein, which

normally from its strike and dip would disappear, is continually thrust up by close set faults, so as to persist in the workings.

On the east drifts the faults have a north-south trend, while those of the south drift are essentially at right angles; therefore the vein may be considered for the sake of clearness as cut by two intersecting systems of faults, one striking north and south and the other east and west. By the former the vein is



Curved faulting of vein. The Montana Tonopah mine.

repeatedly upthrust on the east, and by the latter repeatedly upthrust on the south.

In order to understand the resultant effects of such intersecting faults, let us take a simplified example. Let us take a rectangular block which has been affected by two sets of vertical faults striking at right angles to each other. The result is that lines or planes of equal displacement are zigzag, made up

of regularly alternating portions of each of the two fault systems, while the trend of the whole zigzag, and therefore of the lines of equally displaced blocks, is diagonal to both the fault systems. From this simple case the variations and irregularities may be ideally deduced. In all cases it appears to hold good that the zones or blocks of equal displacement, roughly aligned though these may be, trend diagonally between the two fault systems. In the case under consideration the problem takes on an added complexity, because the vein dip enters as a factor. The dip in this case is opposite to the downthrow of the faults, and the angle of the dip and the displacement and spacing of the faults are such that one offsets the other and the vein continues in a horizontal zone. This explains why the drifts all encounter blocks of the same vein, and it follows that other blocks exist on this level so far as this peculiar intersecting faulting and the balance of the dip and displacement is maintained.

In the Montana Tonopah the Macdonald vein has been affected by complex faulting. In vertical section such faults appear nearly parallel to the vein, though curved and branching, and so become now steeper, now flatter in dip than the veins. The line of faulting is not parallel in strike or dip to the vein, however, though it so appears in vertical section. In fact, the flat portions of the fault zone pitch east on the vein at moderate angles, and striae along the faults show that the real direction of movement has been to the east along this pitch. In horizontal section these faults are seen to curve and branch in as complicated a manner as in the vertical section, producing an added complexity.

EUTECTIC COPPER.

The autectic is that mutual mixture which freezes out last, after the ingredient which is, or the ingredients which are, in excess shall have been removed by gradual cooling. In the case of casting copper, some cuprous oxide is sure to be formed; here the eutectic is a mixture of copper metal and 3.4 per cent. of cuprous oxide, or 0.38 per cent. of oxygen. This eutectic can be seen under the microscope as a thin groundmass surrounding grains of pure copper. It is transparent; blue, in reflected, and red in transmitted light. This eutectic may be a source of weakness, as in copper tubes which carry hot and reducing gases, when the resulting action may form fine cracks by forcing the metal apart, a condition popularly known as the "hydrogen disease" of Hehn. This general problem of the eutectic of copper, tin and oxygen has been the subject of a recent paper by O. Bauer in a recent number of the *Zeitschrift für angewandte Chemie*.

ELECTRICAL SECTION.

(Stated Meeting, held Thursday, March 16, 1905.)

The Development of the Manufacture of the Edison Incandescent Electric Lamp—1881-1905.

By J. T. Marshall,

Asst. Engineer, Lamp Works, General Electric Company.

[In this paper the author gives a detailed account of the successive steps in the development of the Edison electric incandescent lamp from the period of its appearance as a commercial product in 1881 to the present.—The Editor.]

The writer has been continuously in the employ of the Edison General Electric Company, and its predecessors, since October, 1881. In that year there were made in the United States about 34,000 very crude looking Edison incandescent electric lamps,the greater number of which were 16 C.P., 100 to 110 volts, and 5.8 W.p.C., or eight lamps per horse-power. Their average life to the breaking point was about 3000 hours, but they declined so rapidly in Candle-power as to be very inefficient long before they broke. Lamps then sold for 65c. apiece, but the cost was more than double this, so that they were manufactured at a loss.

In 1904, there were made in the United States over 45,000,000 Edison incandescent electric lamps, of artistic appearance, the greater number of which were 16 C.P., 100 to 120 volts, and 3.1 W.p.C., or fifteen lamps to the horse-power. The average life to the breaking point of lamps as now manufactured is 800 hours, and until the end of their lives the candle power is very much better maintained than it was in the 1881 lamp at 5.8 W.p.C. If the present lamps were to be burned at 5.8 W.p.C., or at the efficiency at which the old lamps were burned, the life would be 25,000 hours, or over eight times as long as that of the old lamp. Lamps are now sold for an average of 16c. apiece. The number of lamps now made per operator in the

GEOLOGIC MAP OF TONOPAH MINING DISTRICT.

(Spurr.)

Company's factory is several times the number made per operator in 1881.

It is the object of this paper to trace out the development of the lamp to its present stage from the stage in which the writer found it, so as to show what has brought about the improvement in quality and appearance, and the decrease in cost.

It would be interesting to go still further back, and show step by step the development of the lamp in the laboratory before commercial manufacture was begun, but that would lead the writer outside the field of his personal experience, and for that reason it seemed better to restrict this paper to the scope indicated. For the same reason it was deemed advisable to change the subject from "Twenty-five Years of Electric Lighting" to "The Development of the Manufacture of the Edison Incandescent Electric Lamp, 1881-1905, inclusive."

For purposes of comparison, only the 16 C.P., 100 to 120 volt typical lamp of its time will be considered.

In 1881, the Edison lamp consisted of a conducting filament of carbon enclosed on a vacuous glass globe, and connected through leading-in wires to a source of electric current, which caused the filament to glow. The component parts of the lamp were the filament of carbon, the leading-in wires to which the filament was attached, the glass stem into which the wires were sealed, the joint or clamp by which the filament was secured to the wires, the bulb into which the stem with the filament on it was sealed, and the base to which the exterior ends of the leading-in wires were attached and which, when screwed into the socket, connected the filament to the source of current.

The Edison lamp of to-day has the same component parts; not one has been added, unless the anchor be considered an addition, nor has any one been taken away; all have been more or less modified and improved.

In Fig. 1 are shown the lamp of 1881 and the lamp of 1905.

A is the filament. In the old lamp it is hair-pin shaped and made from carbonized bamboo. In the new lamp it is coil-shaped, thinner, and about twice as long as in the old lamp, and is made from carbonized artificial cellulose.

B shows the leading-in wires of platinum. In the old lamp they are longer than in the new lamp.

C is the stem made in both lamps from a piece of glass tubing.

D is the joint or clamp. In the old lamp it is made of a piece of flattened copper wire folded over the shank of the filament and copper-plated to it. In the new lamp it is made of carbon paste which cements the filament direct to the platinum wire.

E is the bulb. In the old lamp it was "free blown," so that no

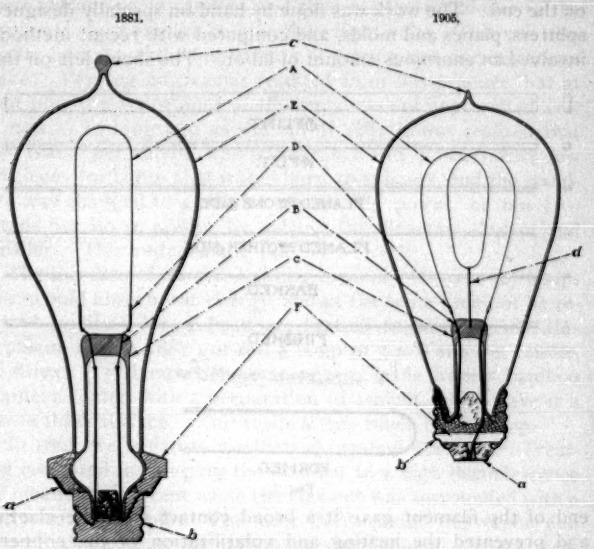


Fig. 1.—The Edison Lamp in 1881 and 1905.

two bulbs were the same size and shape. In the new lamp it is moulded, so that all bulbs are just alike.

F is the base. In the old lamp it consists of a brass ring (a) and a screw (b) assembled and secured to the lamp with plaster of Paris. In the new lamp it consists of a cap (a) and a shell (b) assembled with molten glass and secured to the lamp with a special cement.

c is the tip left from closing the lamp after exhaustion.

d is an iron wire support or anchor to stiffen the filament, and is the only part in the new lamp that does not appear in the old one.

The bamboo splint from which the filaments were cut was 11″ long, $\frac{3}{8}$″ wide and about $\frac{1}{16}$ of an inch thick with the bark or skin on. It was submitted in turn to the operations of splitting into strips, planing off first one side and then the other, shaving off the bark, and cutting out between the shanks on the end. The work was done by hand on specially designed splitters, planes and molds, and compared with recent methods involved an enormous amount of labor. The shank left on the

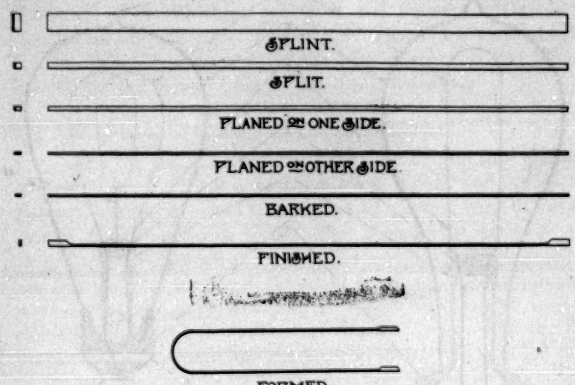


Fig. 2.

end of the filament gave it a broad contact with the clamp, and prevented the heating and volatilization of the copper-plated clamp which would otherwise have occurred.

Fig. 2 shows the filament after each operation.

The shank was very objectionable. It complicated the operation of cutting the fibre, and fixed the length of the fibre so that it could not be subsequently changed to produce different candle-powers and voltage. The filaments were carbonized by heating them in forms stacked in a closed cubical plumbago crucible. At first only one filament was put in a form and the shank prevented more than a few being put in under any cir-

cumstances. The substitution of the carbon paste, which did not volatilize with heat, for the copper-plated clamp which did, permitted the abandonment of the shank, so that filaments could be cut somewhat longer than they were to be used in lamps, more of them could be packed in forms, and they could be cut after carbonization to the length which would give the right volts. It was customary at one time to take sample carbons from each crucible, make them into lamps, determine their voltage at 16 candles, and then cut the remainder of the filaments short enough to give their right volts. This was necessary because of the uncertainty of getting two carbonizations alike. Varying efficiencies resulted from this practice, but at that time the importance of efficiency was not appreciated as it is now. As long ago as the fall of 1881 it was realized that 5.8 Watts per candle was undesirably and unnecessarily low efficiency for lamps that would burn 3000 hours, and the standard was changed to 4⅔ Watts per candle power, or ten (10) lamps per horse power, by cutting the filaments shorter and smaller. This reduced the life.

The increase of electric lighting created a demand for lamps that would absorb less energy, and at the same time not be reduced in life. Mr. Edison set himself to working out this problem, and in 1887 got out a lamp of 3.1 Watts per candle, or fifteen (15) lamps per horse power, made from a bamboo filament coated with a preparation of asphalt, which gave it a dense shiny surface. This made a very much better lamp.

In 1892, we began to use treated bamboo filaments. Treating consisted in bringing the filament to a high incandescence by means of a current while the filament was surrounded with a hydro-carbon vapor. The heat decomposed the vapor and deposited a coating of carbon on the filament. There were several distinct advantages in treating. Not only the right voltage, but also the right efficiency could be obtained from a given size filament by cutting it the right length and treating it to the right resistance, and we began to make the filaments longer and smaller. The treated bamboo filament had a longer life than the untreated bamboo filaments. The increased life was due to the fact that the character of the treated surface was such that at a given efficiency the temperature of the filament was lower.

It was not long after this that we began to use what is called the squirt filament. This is produced by dissolving cotton in zinc chloride or acetic acid, and squirting it through a small hole into alcohol or water to harden it. In this way many hundred yards of round, smooth filament of nearly uniform cross-section may be squirted from the contents of a quart bottle of solution. This filament has to be washed, dried, shaped, packed in crucibles, and carbonized. The squirt method of producing filaments is so much more efficient than making them from bamboo that only between three and four per cent. as much labor is required, and very much less material. The squirt filament besides being longer lived than the bamboo filament has the advantage that it is possible to get it any desired length, whereas the longest possible length to get bamboo between the joints is fifteen inches (15″), which will make a filament less than twelve inches (12″) long.

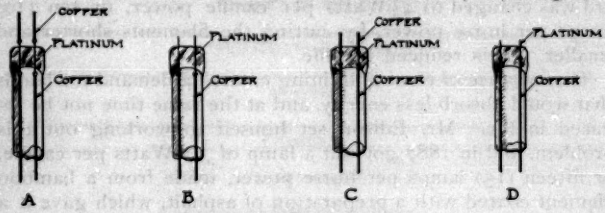


Fig. 8.

To get the full benefit of the treatment on a filament it is necessary that it should not be less in thickness than a well defined minimum, and this thickness can only be obtained by using filaments much smaller in cross section and much longer in length than either the treated or untreated bamboo filaments. This increased length is what makes it desirable in the latest type lamp to have an anchor to steady the filament. The treating process, of course, involves additional operations and consequent additional expense, but the improvement in the quality more than compensates for the additional cost.

The leading-in wires are of platinum welded to copper. Platinum is used because it can be sealed into glass and make an air-tight joint. Many substitutes have been tried with some degree of success, but we have never felt that it would be

safe to adopt any of them. The wires in the old lamp were $\frac{1}{2}$" long, and .012" diameter, as shown in Fig. 3,—A for copper clamps and B for paste clamps. They were made as long as they were to avoid having the weld between the copper and platinum put in the glass seal, and they were made as large as they were to prevent mechanical breakage of the platinum just where it entered the glass. Later the size was reduced to .010". Long before the welds were put in the glass, it was repeatedly suggested that it should be done to permit the use of shorter platinum, and to transfer the strains to the copper, which was stronger. The suggestion was always met by the

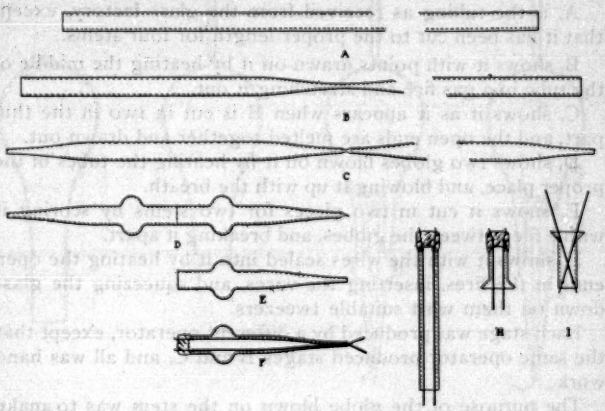


Fig. 4.

statement by the head glass blower: "That was tried at Menlo Park, and it caused all the glass seals to crack." In the meantime the price of platinum was rising, and Mr. Edison set about to reduce the amount of platinum. He did this, as shown in Fig. 3 C, by using a piece of platinum $\frac{1}{8}$ of an inch long and .005 inches diameter, thereby reducing the amount of platinum to $\frac{1}{16}$ of what had been used before. This piece of platinum was completely embedded in the glass, and copper wires protruded both into and out of the lamps, leaving four (4)

welds in the seal; just why these failed to crack the seals was never explained. The .005 wire was large enough to carry the current, and being relieved of all mechanical strain met all requirements, the copper wire was not found advantageous to clamp the filament to, and was abandoned as a clamp wire, after many inferior lamps had been made; the platinum wire was then run into the lamp, but the weld was kept in the seal, as shown in Fig. 3 D. The amount of platinum now used in a lamp is about one-eight as much as was used in 1881.

Fig. 4 shows an inside-part or stem in the various stages of manufacture, as it was made in 1881.

A, is the tubing as received from the glass factory, except that it has been cut to the proper length for four stems.

B, shows it with points drawn on it by heating the middle of the tube in a gas fire and stretching it out.

C, shows it as it appears when B is cut in two in the thin part, and the open ends are melted together and drawn out.

D, shows two globes blown on it by heating the tubes in the proper place, and blowing it up with the breath.

E, shows it cut in two pieces for two stems by scoring it with a file between the globes, and breaking it apart.

F, shows it with the wires sealed into it by heating the open ends in the fires, inserting the wires, and squeezing the glass down on them with suitable tweezers.

Each stage was produced by a different operator, except that the same operator produced stages B and C, and all was hand work.

The purpose of the globe blown on the stem was to make the stem fit into the bulb when the bulb was blown off, and just here it will be well to consider the bulb sufficiently to show its relation to the stem.

Fig. 5 shows the free blown bulb of 1881.

A, just as it was received from the glass works.

B, with the tube attached to the top, through which the lamp is to be subsequently exhausted, and with the neck blown off ready to seal the stem into it.

C, with the stem inserted ready to be melted to the neck of the bulb.

D, with the stem melted in.

To do this the operator held the top tube of the bulb in one hand and the stem in the other, and rotated them in the fires, holding the combination horizontal during the process. In melting the stem and bulb together there was a tendency for the glass to contract and thicken, so that it was blown into from the top and also from the bottom from time to time to keep it in shape. The globe on the stem was blown somewhat thinner than the rest of the stem, and this was thought to prevent a tendency to crack where the stem and bulb were joined together. That part of the stem which projected below the

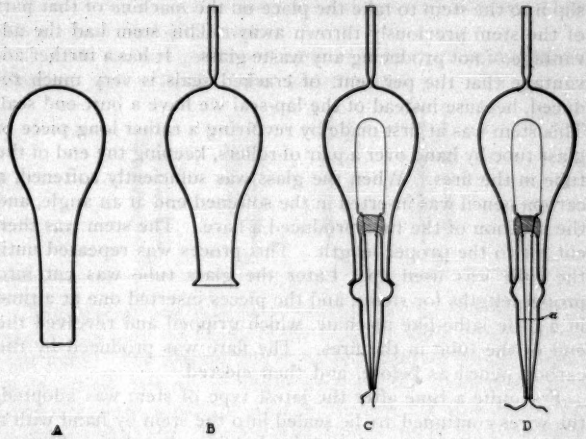


Fig. 5.

lamp was cut off, and thrown away. The only purpose of this waste glass was to form a handle for the operator during the process of sealing it.

The first departure from this type of stem is shown in Fig. 4 G. Here the globe was omitted, and at the same time a machine was designed which held the bulb and stem in position, and rotated them in the fire while being sealed together. There was still a piece of waste glass to be cut off and thrown away, and there was a further disadvantage in this type of stem, that in melting the glass of the bulb down on the glass

of the stem there were unequal strains produced, which caused a good many cracked seals. If the stem was of softer glass than the bulb, the crack took place across the joint; if the stem was of harder glass than the bulb, the crack took place along the joint. It is not easy to obtain glass always alike, so it is necessary to adapt methods suited to these variations.

Fig. 4 H shows the stem now used. This is made from a piece of tubing cut the proper length and flared at one end. It could be sealed into the bulb on the same machine used with the previous stem, but it was necessary to have a holder to slip into the stem to take the place on the machine of that part of the stem previously thrown away. This stem had the advantage of not producing any waste glass. It has a further advantage that the per cent. of cracked seals is very much reduced, because instead of the lap-seal we have a butt-end seal. This stem was at first made by revolving a rather long piece of glass tube by hand over a pair of rollers, keeping the end of the tube in the fires. When the glass was sufficiently softened, a carbon pencil was inserted in the softened end at an angle, and the rotation of the tube produced a flare. The stem was then cut off to the proper length. This proces was repeated until the tube was used up. Later the glass tube was cut into proper lengths for stems, and the pieces inserted one at a time in a little lathe-like machine, which gripped and revolved the end of the tube in the fires. The flare was produced by the carbon pencil as before, and then ejected.

For quite a time after the latest type of stem was adopted, the wires continued to be sealed into the stem by hand with a small specially-designed tool for holding the glass. Later a machine was designed to hold the glass and wires, rotating them in the fires, and squeezing the melted glass down on the wires. The relative positions of the glass and wires on this machine are shown in Fig. 4 I. The machine had four rotating holders, each of which could be successively revolved in four different positions; following one of the holders around in all four positions; in the first position the stem and the wires were placed on the holder; in the second position a soft flame played on the lower end of the tube to heat it slowly to prevent cracking; in the third position a sharp flame played on the lower end of the tube to thoroughly soften it, and a pair of pincers squeezed

the glass on the wires. In the fourth position the finished stem was unloaded from the holder. This machine increased the output of an operator, and had the further advantage of bringing the ends of the platinum wires up against a stop, so that both wires protruded an equal amount beyond the end of the glass. This was one of the factors which entered into the problem of shortening up the platinum wire.

The joint made in 1881 is shown in Fig. 6, A to C inclusive.

A, with short pieces of copper wire welded to the platinum wires.

B, with the wires bent over hook-shape, and flattened on an anvil with a blow of a hammer.

C, with the flattened hook bent over on itself enclosing the filament, and with the joint copper-plated.

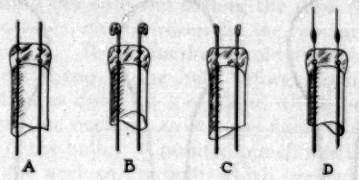


Fig. 6.

The plating was necessary, because the folding of the flattened wire over the shank of the filament made a bad mechanical joint. The plating was done in a wooden trough, having holes in the bottom in which were placed perforated rubber corks, through which the tube of the stem fitted so as to make a water-tight joint. The wires at the bottom of the stem below the trough were all connected together electrically to one pole of a battery, and there was a grid of copper in the bottom of the trough connected to the other pole of the battery. The trough was filled with a sulphate of copper solution, and the stems were slipped in the perforated corks until the liquid came the proper height on the clamps, and the plating was continued until the proper thickness was attained. Plating was a very cumbersome, and expensive operation, and was soon superseded by the paste joint, as shown in Fig. 6 D. The paste as first used was a mixture of very fine graphite, Chinese ink, and water. This answered the purpose pretty well, but the

joints were not as strong as desirable, and there were certain ingredients in the binding material of the ink which caused a discoloration of the bulb, so that this clamp was afterard superseded by one containing certain proportions of graphite and gum, and this is the kind of clamp used at the present time. Since the time the paste clamp was adopted, the clamping has been done by daubing a small quantity of paste on both the platinum wire and the end of the filament, and sticking the two together. This was the method when paste as first adopted, and it is still the method; that is, it is one of the operations in

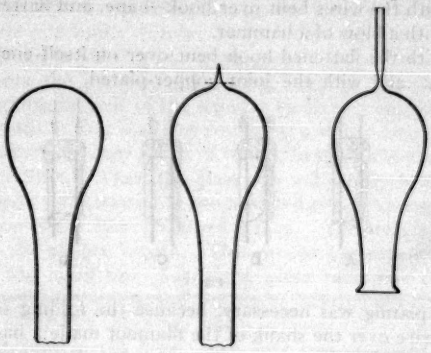


Fig. 7.

which we have practically made no improvement in the last fifteen years.

The bulbs, as heretofore stated, were first made free blown, so that no two bulbs were the same size and shape.

Fig. 7 shows the bulb in the different stages of manufacture.

A, just as received from the glass works.

B, with a tip drawn or punched on the top, to be cut off as indicated on the dotted line so as to leave a small hole.

C. with the short glass tube attached to the top, and with the neck blown off for the reception of the stem.

In the early stages of lamp manufacture the bulbs were sent to the operators who sealed the stems into them in just the condition that they were received from the glass works, except

that they were washed. The operator heated a small spot in the top of the bulb, stuck a stick of glass into the heated part, and pulled out a slight point, which he cut off with a file. This left a hole in the top of the bulb. To this hole he joined a short piece of tubing through which the air was subsequently to be exhausted from the bulb. Then he picked up one of his stems, and by comparing it with the bulb he saw the length that the bulb should be cut. He cut off this bulb by rotating it in the fires at the proper place, pulling off the neck and blowing out the melted end. Then he sealed the stem and bulb together as previously described, attached little glass prongs just below the joint of the stem and bulb to serve as anchors to hold in the plaster of the base, and cut off the stem below the joint. It was soon found advantageous to divide the operations of tubulating the bulb and sealing the stem into the bulb among two operators, one of whom did the tubulating, and the other the sealing-in. It was further found advisable to punch the little tip in the top of the bulb before sending it to the tubulator. This was done on a machine which held the bulb in a vertical position, neck up, over a gas flame which heated a spot in the top of the bulb. A pointed punch was then brought down through the neck of the bulb, which pressed the tip out. After these operations had been separated for some time, they were again brought together by supplying each operator with a bulb punching machine, on which one bulb was being heated while another was being tubulated, and in which the punch was operated by the foot. For many years the small top tube was joined to the bulb by hand, but for several years the tubulating has been done on a little machine on which the bulb is held vertical, mouth downward, and the short piece of top tube is held just over the hole in the top of the bulb, so that four small flames were directed on the point of juncture at the same time that the bulb and tube are slowly rotated. When the two are melted together, the joint is stretched a little so as to produce a contraction, as shown in the figure. At the same time that this machine was designed, a machine was designed for making the hole in the top of the bulb. This was done by heating the top of the bulb with a very small sharp-pointed gas flame at the same time that air pressure was introduced into the interior of the bulb. When the glass became soft enough, the

air forced its way through and made a hole, whose size could be regulated by the air pressure. With high pressure the glass yielded when only a very small area of glass was heated, and the hole was consequently small; low pressure did not blow through so soon, and made a larger hole. The machine for making the hole in the top of the bulb, and for tubulating the bulb was worked by one operator. The use of the tubulating machine resulted in more and better work.

The method of blowing off the bulb suited to each particular stem resulted in the production of lamps which varied considerably in length from the bottom of the base to the top of the bulb. It also resulted in a great difference in diameter where the base was attached to the bulb, so that there was always a compromise between making bulbs to fit the base, and making bases to fit the bulbs. With the advent of the tube stem, it was found that the bulb could be made to fit the base better by blowing it off about one-half inch below the point where the diameter of the neck was the same as the diameter of the shell, and bulbs were gauged out into different lots according to the length from the top of the bulb to the point where it was the diameter of the shell, and different length bulbs were used for different candle-power lamps. Soon after the bulbs began to be gauged in this way, a machine was designed for blowing off the necks of the bulbs before they were sent to the sealers-in. This machine rotated the bulb rapidly in a horizontal position, and had guides which brought the bulb in the proper place to be blown off correctly. Later a blowing-off machine was devised, which held the bulb in a vertical position, neck downward, and at the same time rotated it in the fire. When the glass was sufficiently heated, the weight of the neck caused it to drop off, and at the same time air pressure was introduced through the top of the bulb, and blew off the film of glass which naturally formed over the mouth. This latest blowing-off machine is placed opposite the sealing-in machine, so that the same girl operates both.

The force of habit is very well illustrated in the development of glass-blowing machinery at the factory. A hand operator naturally holds his work in a horizontal position, and this habit seems to be the only explanation for the fact that the first flaring machines, the first sealing-in machines, and the first blow-

ing-off machines all held the work in a horizontal position. This was very awkward, because a holder had to be provided which held the parts positively, and the tendency of gravity was to get the work out of symmetry. When machines were devised which held the work in a vertical position, it was only necesary to drop the parts on holders, where they tended always to assume a symmetrical form. It now seems strange that anyone should have attempted to perform these operations in any other position.

In speaking of the stem tube mention was made of the fact that a machine was designed which held the bulb and stem in position, and rotated them in the fire while being sealed together. As this machine held the work in a horizontal position, it was not easy to get a holder for the latest type of stem, which would fit all of the stems. Glass tubing is made now in the same way as it was many hundred years ago, and it is not possible to make it uniform in diameter. Hence, the necessity of making a holder which would fit all diameters of tubes. The difficulty of doing this is probably what first suggested holding the stem in a vertical position, and a machine was devised very similar to the machine used for making stems; in fact, it was used before the stem-making machine was developed. The four holders are adapted so that the stem is set on a stud which runs up inside of it, and the bulb is slipped over the stem with the filament on it, and rests on a holder so that the neck of the bulb and the flare of the stem are in the proper relative positions. This is done in the first position of the holder. In the second position, a soft flame is directed at the place where the joint is to be made. In the third position, the two are melted together in a hot flame, and in the fourth position the lamp is removed from the holder.

The desirability of having bulbs uniform in size was apparent very early in the history of lamp manufacture, and from time to time bulbs blown in moulds were tried. With the earlier type of stems it was found that the number of cracked seals was very much increased, and so free-blown bulbs were used for a long time after we wished to abandon them. When the latest type of stem was adopted, it was found that they could be sealed into moulded bulbs with very little breakage, due to the

different character of the joint, and the moulded bulb was adopted, and has been in use for about fifteen years.

In Fig. 8 are shown the different stages of development in the base.

A, with the ring and shell assembled with plaster.

B, with the cap and shell assembled with plaster.

C, with the rim of plaster left off at the top.

D, with the shell and cap assembled with porcelain, and attached to the lamp with plaster.

E, assembled with glass, and attached to the lamp with plaster.

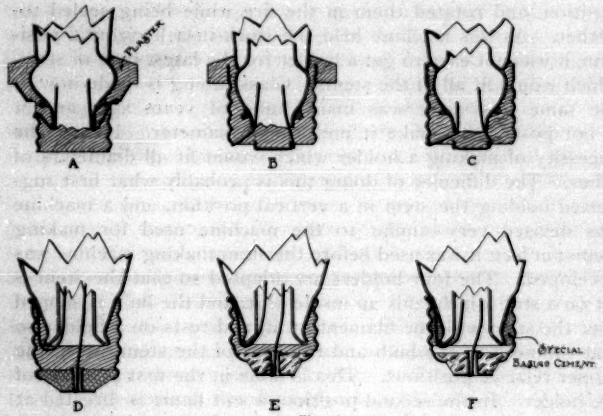


Fig. 8.

F, assembled with glass, and attached to the lamp with a special basing compound.

In A, B and C the brass parts were placed in a mould, which was then filled up with plaster of Paris, mixed thin enough to be poured. The lamp was set into it and allowed to stand until the plaster hardened. The thick rim of plaster at the top of A was necessary in order to make the plaster strong enough to hold the rim. It was soon found that screwing the lamp into the socket put a tensile strain on the plaster, and easily broke it apart. For this reason the base made with the cap on the bot-

tom instead of a ring at the top was substituted. Screwing this base into the socket caused compression instead of tension, which the plaster was better able to sustain. At first this base had the thick rim of plaster at the top, not because it was necessary for strength, but because the shells did not fit the neck of the lamp, and it was thought to present a better appearance. Later the rim was abandoned, and this left some exposed plaster between the shell and the neck of the lamp. Very often the lamp was not set centrally in the shell, and this presented a bad appearance. To overcome this the shells were turned in at the top to different diameters, and the lamps were sorted out to fit the different diameter shells. Later when the tube type of stem was adopted, it was found that the bulb could be blown about one-half inch below the point at which this diameter was the same as that of the top of the shell, and shells were afterwards made turned in all to the same diameter. This enabled us to use one type of shell, but it resulted in a still greater variation in the length of the lamp from the cap to the top of the bulb. All of this trouble was corrected when the moulded bulb was adopted, because the bulb was moulded with a shoulder, under which the top of the shell fitted.

The method of assembling with plaster was very slow because it required about one-half hour for the plaster to harden sufficiently to be taken out of the mould, and one operator had to use about 100 moulds, so that the floor space required was very great. There were also objections to plaster, on the ground that it had a tendency to absorb moisture, and when in use in moist places there was occasionally a current from one wire to the other wire in the base, which gradually ate away the wire and broke the connections. This led to the adoption of the present method. This involved the assembling of the screw and cap together before placing it on the lamp. This assembling was first done with a sort of vulcanite composition, afterwards with a piece of porcelain, and still later by assembling with molten glass. The operator now picks up the base, and smears into the inner upper edge of the shell a quantity of the basing compound sufficient to fill up the space between the shell and the neck of the lamp. Then she threads one of the leading-in wires through the hole in the cap, and shoves the base down on the lamp, adjusting it by eye so as to

be symmetrical. Then she places it, base up, in a furnace, in which the compound is heated up to melting point so that it adheres firmly to both the base and the lamp. The protruding wires are then cut off, and soldered respectively to the shell and cap. The soldering is done by putting a little soldering paste on the wire where it touches the cap, and holding it up against a thinned pointed rod of copper heated by a gas flame. The method of soldering is practically the same as it was in 1881; that is, it is one of the few operations in which practically no improvement has been made.

So far the visible elements of the lamp have been considered and little or no attention has been paid to three very important processes, viz.: carbonization, exhaustion, and testing.

Our present method of carbonization applied to the bamboo filaments of 1881 would probably not make them any better than they occasionally were, but it would make them all as good as the best. The improvement in carbonization has been mainly in the line of increasing the production, at the same time that it has resulted in a much more uniform product. The important things in the carbonization are to keep the air away from the filaments so that they will not oxodize, and to raise the temperature so slowly that the volatile constituents of the filaments shall not be expelled so rapidly as to cause fractures in their structure.

At first filaments were carbonized in little nickel forms which were nothing more than extremely shallow boxes stacked up one above another in plumbago crucibles, so that each box served as a cover for the one just below it. and each box contained but one filament. Nickel forms did not permit of high enough temperature without being destroyed, and similar carbon forms were soon substituted. Later, when shankless filaments were used, deeper boxes were substituted for the forms, quite a large number of filaments were placed in them, and the boxes were filled with a packing material to keep the filaments in shape.

Squirt filaments at present are packed without forms in cubical crucibles. Fig. 9 shows a bunch of filaments.

A layer of these bunches is placed in the bottom of the crucible and covered over with a packing material, such as sawdust, or similarly finely-ground substances; then successive

layers are put in until the crucible is full. The purpose of the packing material is to hold the filaments in place and shape. Carbonizing results in a cubical block sufficiently tenacious to hold together, but friable enough to be easily broken apart to get out the filaments. It will readily be seen that by the modern method of packing many more filaments can be put in a

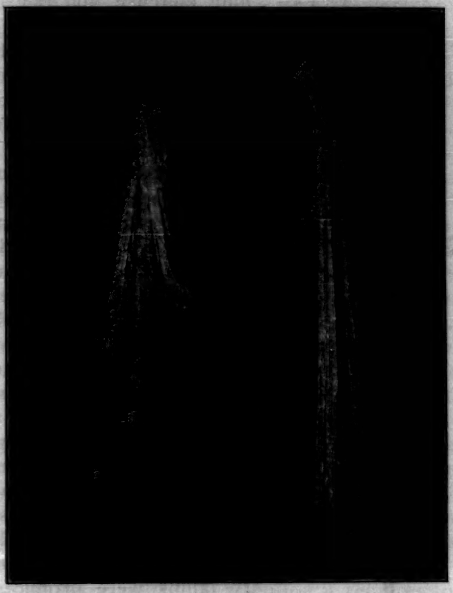


Fig. 9.

crucible than when they were packed in forms, one filament in a form.

At first carbonization was done in a brick furnace, burning coal with artificial draft, but later a preliminary heating was given in a cook stove. Still later gas furnaces were used, one type for the preliminary heat, in which a dull red was obtained, and another for the final heat, which brought the temperature to about the melting point of platinum.

In 1881 and until 1895, all lamps were exhausted on Sprengel pumps, as shown in Fig. 10. Mercury from a reservoir flowed down through a contraction (a) which limited the amount of flow, into the tube (b) which served as a cushion for the dropping mercury, and ran across the tube (c) into the tube (d). This tube, a short distance below (c) was of smaller bore, so that as the mercury came down, it trapped bubbles of air which it carried along to the bottom of the tube, where it escaped. At the joint (e) a phosphorus cup was connected, in which was placed a small quantity of phosphoric amhydride, and at the joint, (f) the top tube of the lamp was inserted. The purpose of the phosphoric anhydride was to absorb water vapors in the lamp. It took from one-quarter of an hour to five hours to exhaust a lamp with such a pump. As good vacuum, and consequently as good lamps can be obtained from a pump of this kind as from any of the more recent pumps, but as a matter of fact, through no fault of the pump, large numbers of poor quality lamps were produced in the early history of lamp manufacture, because there are many details in the process of exhaustion which require most careful attention to produce good results. For quite a number of years after we began the manufacture of lamps we alternately made good and poor lamps without knowing it, and the peculiarity of these poor lamps was that they gave longer life than the good lamps. This was because the condition of the vacuum was such that it changed in the early life of the lamp, and reduced the candle-power of the

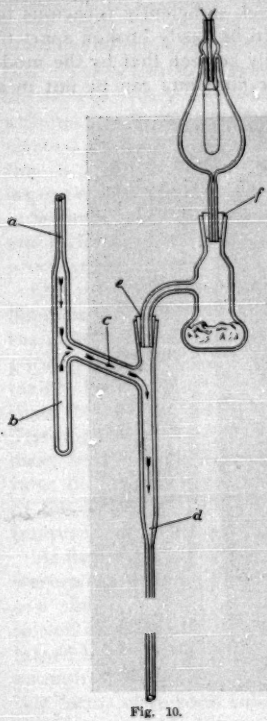


Fig. 10.

filament very much below the initial candle-power. At this low candle-power the filament could burn a very long time without being destroyed.

The use of mercury produced unsanitary conditions. Pumps were continually breaking, the mercury was spilled on the floor. In warm weather the air of the room was saturated with mercury, and the men after a time became chronically ill with it.

Mechanical pumps were tried from time to time, but were not adopted until an Italian, named Malignanni, discovered that by introducing the vapor of red phosphorus into the lamp at just the right time in the exhaustion, a good vacuum was obtained by the combination of the phosphorus with the residual vapors in the lamp. The red phosphorus, previous to tubulating, was painted on the inside of the top tube, and when the vacum was at the right stage, the lamp was shut off from the pump, and the tube heated on the outside to vaporize the phosphorous, which then spread out in the lamp. The right stage of vacuum for the introduction of the phosphorus was indicated by the condition of a blue halo which appeared in the lamp when lighted to the right degree of incandescence while on the pumps, and the proper combination of the phosphorous and residual vapors showing that the vacuum had been obtained was indicated by the total disappearance of this halo. At this stage the little contraction where the top tube is joined to the bulb was melted off with a torch, and the lamp as a lighting device was practically finished.

By the old mercury exhaust a gang of four men attended to about 100 lamps. With the red phosphorus exhaust each operator has a pump and, exhausting one lamp at a time, can give each lamp the individual attention it requires to give the best results.

It is rather a remarkable fact that the red phosphorus method of exhaustion is not applicable to lamps of less than 30 volts, and these lamps, while exhausted on the same kind of mechanical pump as is used with the red phosphorus, require about ten minutes for the exhaustion.

All lamps after exhaustion are tested for vacuum on an induction coil. If the vacuum is not good, Crookes tube effects are produced.

The early method of testing a lamp for volts consists in putting it on a photometer with a rheostat connected in series with it, and a volt meter connected around it, bringing it to 16 candle-power by means of the rheostat, and reading the meter. To get accurate results a very constant source of current was necessary, and this was obtained by hand regulation of the field magnets of the generator. The man who regulated the voltage was placed near the photometer, and called out whenever the voltage was wrong, so that readings should not be taken at that instant.

A photometer whose accuracy did not depend on the voltage of the circuit being right was put in use about 1885. This is what is called the Sliding Scale Photometer, and is still in general use.This photometer is wired up with the lamps at each end of the bar in multiple, so that both have the same voltage over them, and the voltage of the lamp to be tested is determined by the position of the screen on the bar when in balance.

The calibration of the volt scale is made by taking a number of lamps previously tested on a standard photometer, and selected for each voltage from, say 100 to 120 volts, selecting a lamp of about the middle of this range for a standard to be used permanently at one end of the photometer, and placing the other lamps in turn on the other end of the photometer, moving the screen to a position of balance, and marking on the scale opposite these positions the corresponding voltages of the lamp. The principal advantage of this photometer is that fluctuations in line voltage do not affect its accuracy, because they affect both lamps in the same proportion, and do not alter the position of balance. The production is also increased through not having to read volt meters and indicators.

Perhaps the element which has contributed as much to the improvement of the lamp as any other is inspection. Inspections have been gradually instituted all along the line of manufacture, so that at present we make from first to last fifteen (15) inspections, in each of which from five to six defects are sought for.

Fig. 11 is a table showing the change in the life of the lamp coincident with changes in its elements and the method of its manufacture. The later improvements, corresponding to different periods, were obtained, not by elemental changes in the

lamp, but by a very gradual improvement in the processes. When the importance of maintenance of candle-power began to be appreciated, it was necessary to decide at what per centage of its initial candle-power a lamp was no longer useful and would better be taken down and destroyed rather than be allowed to burn longer. This point has by common consent come to be fixed at 80 per cent. of the initial candle-power.

It will be noted from Fig. 11 that for the earlier lamps the life to 80 per cent. was not given. This is because we did not know the importance of ascertaining this factor, and did not suppose it was anything like so great as we afterwards found it to be. It will also be seen that as the life to 80 per cent. first began to increase, it was accompanied by a very decided decrease in the actual life. The previous long life, as heretofore explained, was due to the rapid diminution of candle-power,

Type of Filament	Date	Watts per Candle	Actual Life Hours	Life of 80 % of Initial Candles Hours
Plain Bamboo	1881	5.8	3000	
" "	1881	4.66	900	
Asphalted Bamboo	1888	3.1	1000	200
Treated "	1893	3.1	1200	260
" Squirt	1896	3.1	700	370
" "	1900	3.1	750	425
" "	1904	3.1	800	475

Fig. 11

and the consequent low temperature at which the filament burned. The 1896 lamp, although having a very much shorter life than the 1893 lamp, is really a much better lamp because of the longer life to 80 per cent. It has been the practice of the Company from the beginning without any intermission to make life tests on lamps, both regular product and experiments.

In comparing the quality of lamps it is necessary to consider three items: Candle-power, the energy consumed, and the life. Numerous tests have shown the comparative lives of lamps at different efficiencies, and in making comparisons we always

caluclate what the life would be at some given efficiency, say 3.1 Watts per candle-power.

Fig. 12 is a table showing the life we can expect from 16 C.P. lamps of different efficffiiency.

These lamps are all the same quality, and if burned at the same temperature would not vary greatly in life. The very great difference in life is due to the difference in temperature. The 80 Watt lamp has four and a-quarter times the surface of the 32 Watt lamp, and the light per unit of surface, and consequently the temperature is very much less. Without going into a calculation, it will be evident at the usual prices of lamps and electrical energy that the 32 Watt lamp, though taking lit-

Watts	Life to 80% of Initial Candles Hours
32	28
40	132
48	412
56	1000
64	2005
72	3570
80	6125

Fig. 12

tle energy, will not be economical, because of the very short life, and consequent frequent renewals. On the other hand, it will be seen that the 80 Watt lamp, though having a very long life, will not be economical because of the large amount of energy used. Depending upon the cost of the lamps and the cost of electrical energy, the most economical lamp to use under a given set of conditions can be determined, and it is almost certain to lie somewhere between the extremes in Fig. 12. In general, the higher the cost of the electrical energy and the lower the cost of the lamp, the higher the efficiency which should be selected.

The 3.1 W.p.C. lamp at the time of its adoption was of too high an efficiency on account of the short life to 80 per cent. of initial C.P. This was not then appreciated, but it is now.

With the subsequent improvement in quality, the life became quite satisfactory. If some improvement in lamp manufacture should greatly increase the life that a 3.1 W.p.C. lamp can be made to give, it is probable that this improvement would be taken advantage of to make the lamp more efficient rather than to prolong its life.

DISCUSSION.

MR. WM. J. HAMMER.—I have enjoyed listening to Mr. Marshall's very interesting paper dealing with the improvements in manufacturing process of the Edison incandescent electric lamp from 1881 to 1905, and one fact struck me as of extraordinary significance. Mr. Marshall said, with the possible exception of the anchoring wire which might even be excluded from consideration, that the Edison lamp of to-day embodies every feature of the lamp of 1881. He might even go back as far as 1879, for Edison's lamp of that year embodied every essential feature to constitute a successful and commercial incandescent electric lamp; *i. e.*, a high resistance filament of carbon hermetically sealed in an all-glass receptacle, with platinum leading-in wires passing through the glass. No fundamental principle has been done away with and no new principle added thereto, naught save refinements or improvements in manufacturing details. This is truly extraordinary! Where in the world could we find another inventor of which this could be said with equal force. Where could we find in the arts an invention of so great utility, so widespread in its application which has stood for twenty-five years without a single important change in principle, or salient feature of construction. This, it seems to me, bears splendid testimony to the remarkable genius of Edison and the skill and practicability of himself and those about him at Menio Park, New Jersey. Interesting as Mr. Marshall's paper is in dealing with the Edison lamp subsequent to the year 1881, I wish that it had been possible to have embodied a resumé of the earlier work, say from 1878 to and including 1881. I am sure you would all have found much of fascinating interest. When I found this afternoon that I should be able to run over from New York to attend this meeting, it occurred to me to bring along a large photograph of

my historical collection of Incandescent Electric Lamps, which I exhibited at the recent International Exposition at St. Louis, where it received a Grand Prize, and at the suggestion of Dr. Wahl and Mr. Marshall, this photograph has been hung on this board, where it can be examined later, and I shall be pleased to explain certain of the details to those who care to remain. It represents "The History of An Art," and embraces about one hundred types of lamps, showing the entire development of the Edison lamp from its incipient stages up to the present day, and also the work of the various contemporaneous workers in this field, both here and abroad. I have been working upon this collection for over twenty-five years, the foreign lamps having been collected during sojourns in Europe, embracing about seven years' time.

Mr. Marshall speaks of the treating of the filaments of the Edison lamp as having first been employed in 1892. In this connection I might state that I have both lamps and separate filaments which were treated with hydrocarbon vapors (naphthalene and gasolene) in the year 1880, at Menlo Park, N. J. They are of both the paper and bamboo types of filaments. One other point mentioned by Mr. Marshall which I think might be modified, is that in which he speaks of the falling off of efficiency in the lamp which he says was not appreciated until a comparatively recent date. I had charge of the early life and efficiency tests and records at the Edison Laboratory, and at the first lamp factory at Menlo Park, and remember that to a considerable extent we did understand that there was a falling off in efficiency. The lamps were frequently re-tested and in connection with my records I made a rack containing ten lamps, showing varying degrees of deposit in the globe and each lamp was compared with these standards as one of many tests, and as the filament disintegrated the deposit grew darker, and this was especially noticable in the old copper-clamp lamps. Our photometer, colorimeter and other tests enabled us to know that there was a falling off of efficiency, but the importance of this was naturally appreciated to a greater degree as our knowledge of the art progressed.

MR. MARSHALL.—I agree with Mr. Hammer that a resumé of the earlier work done in developing the Edison incandescent electric lamp would be very fascinating. I have already given

my reason for its omission from this paper. The subject is well worthy of separate consideration, which I trust may yet be given it. I know of no one better qualified to treat the subject than Mr. Hammer, because he was with Mr. Edison when the work was done, and participated in it.

Regarding the adoption of treated filaments in 1892, this has reference to the use of them for commercial lamps. I made life tests of treated filaments as early as 1881, and personally treated filaments long before 1892, but it was until then that practically all our lamps were made from such filaments. Our competitors used them before we did because they owned the patents.

Regarding our knowledge of the falling off in the efficiency of lamps during life, I did not mean to convey the impression that we did not know there was such a falling off. The blackening of the bulb, and the decrease in C.P. was observed before 1881, and our life test records sometimes included a statement of the condition of the bulb as compared with the rack to which Mr. Hammer alludes, but for years our life tests did not always include readings at regular intervals for C.P. at initial voltage, and we did not know how much this falling off in C.P. was affected by variations in the processes of manufacture. Now all life tests do include C.P. readings at regular intervals, and we have a very accurate knowledge of the effects of variations in manufacturing methods.

Prof. G. A. Hoadley.—I have seen the statement that nickel-steel of a certain high percentage of nickel has the same coefficient of expansion as glass. This will allow it to be used in the seal of incandescent lamps instead of platinum and would make a desirable reduction in the price of platinum for other purposes. Can you give us any information on the results of the use of nickel-steel for the purpose?

Mr. Marshall.—Nickel-steel wire can be made having the same coefficient of expansion as glass, but a coating of oxide forms on its surface in the usual method of sealing it into the glass, and air will slowly leak through this oxide. There is a wire specially made for use in incandescent lamps, consisting principally of nickel and steel. The wire becomes black in the process of sealing into the glass, but air-tight lamps can be made with it. There results a small percentage of leaky lamps,

but enough, however, to make it seem unsafe to substitute it for platinum. We have had similar experience with all other attempted substitutes for platinum that we have tried.

PROF. HOADLEY.—How long can an incandescent lamp be run if it is used in parallel with the lamps under test?

MR. MARSHALL.—Standards for incandescent lamps are usually made of an efficiency of 4 W.p.C. Before being standardized they are burned long enough to make out the early rise in C.P. After that they will decline quite uniformly in C.P. at the rate of 1 per cent. in about 100 hours. It is not customary, however, to use these standardized lamps continuously on the photometer. A suitable unstandardized lamp is placed on the photometer as a working standard. A standardized lamp is placed on the other end, and brought to the proper voltage. Then the working standard is adjusted to read correctly the candles of the standardized lamps. Several standardized lamps are used in turn to check one another, and in practice are used but a few minutes a day, and will consequently last a long time. The working standard is checked several times a day by putting the standardized lamps on the working end of the photometer to see if they are correctly read by the working standard, but several days usually elapse before any readjustment of the working standard becomes necessary.

PROF. HOADLEY.—If the life test of an incandescent lamp is made at a higher voltage and candle-power than the normal, in order to shorten the time of the test, how are the results obtained reduced to those that would be obtained under normal conditions?

MR. MARSHALL.—The relative lives of lamps at different efficiencies is obtained from empirical curves made from plotting the results of large numbers of the same lot of lamps life-tested at different candle-powers. These curves show that approximately the life varies inversely as the 3.6th power of the candle-power.

PROF. RONDINELLA.—Mr. Marshall has stated that in the early days of incandescent lamps the gradual decrease in a lamp's candle-power was overlooked, and it was rated by its original efficiency in watts-per-candle and its life in hours till the filament broke. Just seventeen years ago I read a paper before the Engineers' Club of Philadelphia on "The Items of

Expense in Incandescent Electric Lighting," based on a consideration of the relation which existed "between these two properties in incandescent lamps," combined with the cost of power. I used a quantity of data showing the *life* averages of Edison lamps for all grades of *efficiency* from 2.5 to 4 watts-per-candle, that had been worked up from the results of several thousand lamps used in regular service during the preceding five years, and I deduced the equation of

$$h = \frac{w^{5.7725}}{3.7349}$$

which expressed the relation between *hours* of life and *watts* per candle in exact accordance with the experimental data, except for lamps of less than 100 hours' life. This equation was then compared with the results obtained from the six other makes of lamps tested by the Franklin Institute after its Electrical Exposition of 1884, and found to agree very closely with them also. I should like to ask Mr. Marshall whether the changes in the process of manufacture have altered this relation between life and efficiency in incandescent lamps, or is it probable that the same formula still maintains?

MR. MARSHALL.—I don't think that the relation between life and efficiency in incandescent lamps is any different now than it was twenty years ago due to changes in the process of lamp manufacture. For instance: In Fig. 12 a 48 Watt lamp, corresponding to 16 candles, 3 W.p.C., will have a life of 412 hours. The 64 Watt lamp, corresponding to 16 candles, 4 W.p.C., has a life of 2005 hours. That is, the 64 Watt lamp is practically five times the life of the 48 Watt lamp. Twenty years ago the life of both of these lamps would have been much shorter, but even so, the life of the 64 Watt lamp would be five times the life of the 48 Watt lamp.

RED BERYL represents a new mineralogical anomaly. The crystals are small but distinct; they are colored by some manganese compound, and are found near Simpson Springs, Utah., in the Dugway range. The matrix is rhyolite, and topaz, bixbyite and altered garnets are associated. W. F. Hillebrand is sponsor for this chromatic novelty.

A NEW AND SIMPLE WELSBACH LAMP.

Quite recently there has been introduced in France and Germany a new form of portable lamp, as compact and light as an ordinary kerosene lamp and more easily operated, which has for a fuel supply wood alcohol.

The burner, as compact as the usual kerosene burner, and adapted to fit any regular fount, is of a novel regenerative type, to which the wood alcohol is conducted by a wick. The latter needs no trimming, as the alcohol by the heat is gasified, and then being mixed with air, produces an intense flameless heat above, which renders brilliantly incandescent the usual netted Welsbach mantle, suspended from above and inclosed in a cylindrical slender glass chimney similar to the student lamp type.

This gives in very small compass an intense illumination, equal to forty-five candle-power with the small mantle, and a smokeless light of remarkable steadiness and brilliancy, and which can be perfectly regulated, with the advantage of being odorless even when lowered to bare incandescence.

One of the points of novelty is an automatic device for feeding a minute quantity of alcohol from the fount to the burner in starting, which is done much in the same way as the usual mechanical extinguishing devices are operated on kerosene lamps. The small amount of alcohol thus brought up is simply ignited by a match, as in an ordinary lamp. In about a minute the light burns brilliantly.

On the Continent, where alcohol is made cheaply, a source of illumination is produced fully as economical as kerosene, and much more easily handled.

It has been stated that in this country it is possible to produce wood alcohol more economically than in Europe, because of our large forests, which form an abundant source of supply of wood.

As a light for photographic and projection purposes, it becomes very efficient, inexpensive and convenient.—*Scientific American.*

LIMIT OF SPEED OF THE AUTOMOBILE.

A prominent French automobile engineer recently stated that it would not be possible for a modern racing automobile to exceed the speed of 130 miles an hour while it is maintained at the present weight. M. Serpollet, the designer of the well-known steam car of that name, has therefore decided to approach this maximum as near as possible during this year. He is now constructing a steam car which he is confident will accomplish the kilometer in 18 seconds, or at an average speed of 125 miles an hour. The motor will develop over 200 horse-power, and the weight of the engine without the steam generator or boiler will be only 150 kilogrammes (330 pounds).

A CHOKE-COIL, or a choker, is a coil of many heavy turns, and may be used as a lightning arrester on the theory that a coiled conductor presents more resistance in the case of a current of high frequency of variation than in one of relatively low frequency.

(Stated Meeting, held Thursday, December 8, 1904.)

Electrical Waves and the Behavior of Long-Distance Transmission in Lines.

By W. S. Franklin, Director Dept. of Physics, Lehigh University, Member of the Institute.

[This paper develops Maxwell's mechanical conceptions of electromagnetism and applies them in a very simple and direct way to the discussion of electromagnetic waves.

This fundamental discussion of electromagnetic waves is followed by a discussion of wave distortion on telephone lines. The effect of line resistance and line leakage upon wave distortion is explained and a very elementary statement is given of the reduction of line losses (in pure wave transmission) by the increase of line inductance.—The Editor.]

In the discussion of any class of physical phenomena the choice lies between two methods, one making use of conceptions, generally mechanical conceptions, and the other employing elaborate mathematical developments, usually based upon differential equations. The present purpose is to describe in popular but precise terms, the phenomena of electric waves and especially to give an intelligible account of electric wave distortion. For this purpose the purely mathematical method is utterly hopeless and unfortunately the conceptual method is nearly hopeless also for the reason that the conceptions which one must employ in describing electromagnetic actions are not only unfamiliar but they are, to a great extent, antagonistic to those more or less indefinite but extremely persistent mechanical notions which underlie nearly every one's idea of electricity.

In this discussion I shall make use of Maxwell's cellular theory of the ether and I assure you that you need not concern yourselves with the limitations of this theory. It is more than adequate to our present purpose. I shall devote a large part of the time at my disposal in developing the conceptions of electromagnetic action which are based upon Maxwell's idea of a cellular ether, and in this discussion you are to understand that I am not contending for the truth of these conceptions, I am only insisting on their utility.

Fundamental Conception.—The ether is to be considered as built up of very small cells of two kinds, positive and negative,

in such a way that only unlike cells are in contact. These cells are imagined to be so connected, where they are in contact. that if a cell be turned while the adjacent cells are kept stationary, then a torque, due to elastic reaction of adjoining cells, is brought to bear upon the turned cell, which tends to right it, and which is proportional to the angle turned.

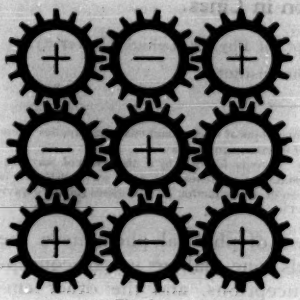


Fig. 1.

For example, the ether cells may be thought of as small cog wheels with rubber teeth, positive cells and negative cells gearing into each other, as shown in Fig. 1. In subsequent figures these cog wheels are represented by plain circles.

Conception of the Magnetic Field.—The ether cells at a point in a magnetic field are to be thought of as rotating about axes which are parallel to the direction of the field at the point, the angular velocitiy of the cells being proportional to the intensity of the field at the point. The positive cells rotate in the direction in which a right-handed screw would be turned that it might move in the direction of the field, and the negative cells

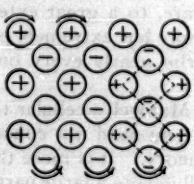


Fig. 2.

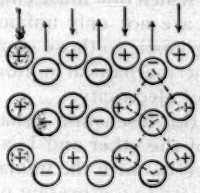


Fig. 3.

rotate in the opposite direction. This opposite rotation of positive and negative cells is mechanically possible since only unlike cells are geared together.

This rotatory motion of the ether cells is indicated in Fig. 2, which represents a magnetic field perpendicular to the plane of the paper, and directed away from the reader; all the positive

cells rotate clockwise, and the negative cells counter-clockwise. The kinetic energy per unit volume in such a system of rotating cells is proportional to the square of the angular velocity, which is consistent with the fact that the energy (kinetic) per unit volume in a magnetic field is proportional to the square of the intensity of the field.

Conception of the Electric Field.—The positive ether cells at a point in an electric field are to be thought of as displaced in the direction of the field, while the negative cells are displaced in the opposite direction; this displacement being proportional to the field intensity. Thus Fig. 3 represents the case in which the positive cells have been displaced towards the bottom of the page relatively to the negative cells. Fig. 4 represents two

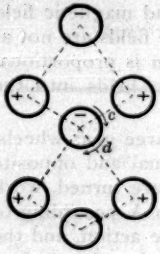


Fig. 4.

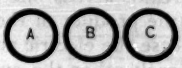


Fig 5.

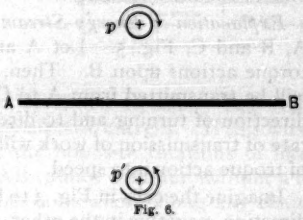


Fig. 6.

meshes. The downward displacement of the positive cells has distorted these meshes, which are normally square. Since this cell structure of the ether is assumed to be elastic, its distortion, as represented in Figs. 3 and 4, represents potential energy. The amount of potential energy per unit volume is proportional to the square of the displacement. This is consistent with the fact that the energy (potential) per unit volume in an electric field is proportional to the square of the field intensity.

The two positive cells to the right of the middle cell in Fig. 4 being displaced downwards, may be conceived to exert troques upon the middle cell, as shown by the arrows *c* and *d*; which troques are proportional to the intensity of the electric field,

i. e., to the displacements of the cells. The cells to the left exert equal but opposite troques upon the middle cell. This troque action which accompanies the distortion of the cell structure of the ether is the connecting link between electric field and magnetic field, and it is the basis of the mechanical conception of electro magnetic action.

The Energy Stream in the Electromagnetic Field.—A region in which electric field and magnetic field coexist is called an electro-magnetic field. It has been shown by J. H. Poynting that energy streams through an electromagnetic field in a direction which is at right angles both to the electric field and to the magnetic field at each point, and that the amount of energy per second which streams across one square centimeter of area is proportional to the product of the electric and magnetic field intensities. In case the electric and magnetic fields are not at right angles to each other the energy stream is proportional to the product of the intensities of the two fields into the sine of the included angle.

Explanation of Energy Stream.—Consider three gear wheels, A, B and C, Fig. 5. Let A and C exert equal and opposite torque actions upon B. Then, if the wheels are turned, work will be transmitted from A to C, or from C to A, according to direction of turning and to direction of troque action, and the rate of transmission of work will be proportional to the product of troque action into speed.

Imagine the cells in Fig. 3 to be rotating, positive cells in one direction, negative in the other, about axes perpendicular to the paper. This constitutes a magnetic field perpendicular to the electric field, which is towards the bottom of the page. On account of the troque actions between the cells, as before explained, energy will be transferred to the right (or left) by each chain of geared cells at a rate which is proportional to the product of the intensity of the magnetic field into the intensity of the electric field, and the energy per second flowing across an area perpendicular to both electric field and magnetic field is proportional to the product of the respective field intensities into the area; for this area is proportional to the number of rows of cells which are acting as chains of gear wheels. The energy stream, that is, energy per unit area per second, is there-

fore proportional to the product of magnetic and electric field intensities, and is at right angles to both.

The Electric Current.—Consider a wire, AB, Fig. 6, along which an electric current is flowing. The magnetic field on opposite sides of AB is in opposite directions, so that positive ether cells at p and p^1 are rotating in opposite directions, as shown. Since an electric current may be maintained for an indefinite time, this opposite rotation of positive ether cells on the two sides of AB cannot be due to an ever-increasing ether distortion (the cells are geared together, as it were), but there must be a slip between adjacent cells somewhere between p and p^1. This slip between adjacent ether cells takes place in the material of the wire, and constitutes the electric current.

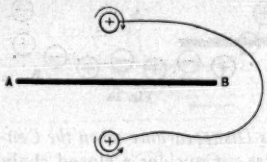


Fig. 7.

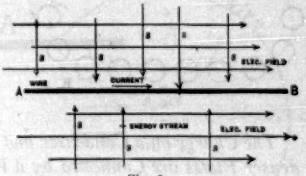


Fig. 8.

Steady electric currents flow in closed circuits. Let AB, Fig. 7, be a wire carrying a steady electric current. If this wire does not form a closed circuit, the opposite rotations of like ether cells on opposite sides of AB cannot continue without adjacent cells slipping on each other somewhere along any chain of cells passing around the end of AB. That is, lines of steady slip of the ether cells are necessarily closed lines. When a current does flow in a circuit which is not closed, and increasing ether distortion (electric field) is produced around the end portions of the circuit, which produces (constitutes) electric charge there, as explained later.

Flow of Energy in the Neighborhood of an Electric Current.—Let Fig. 8 represent the neighborhood of a long wire, AB, through which electric current is flowing. The electric field in the neighborhood is parallel to the wire, and the magnetic field circles around the wire. The product of magnetic field intensity into electric field intensity is the energy stream, and this is directed towards the wire from all sides. This energy stream-

ing in upon the wire changes into heat which appears in the wire. In case the wire is of high resistance, the electric field (volts per centimeter) is of great intensity, and, for a given current (given intensity of magnetic field) the energy stream is correspondingly intense, making the wire very hot. The electric field is not everywhere perpendicular to the wire, especially near the battery or dynamo which is maintaining the current. The energy therefore streams out from the battery or dynamo through the whole region surrounding the wires, and the energy stream turns in upon the wire throughout its length.

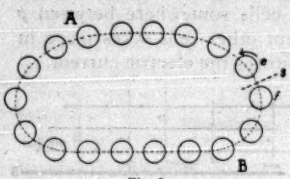


Fig. 9.

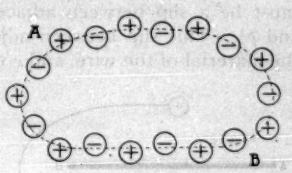


Fig. 10.

The Charge on a Condenser and Its Disappearance when the Condenser Plates are Connected by a Wire.—Consider a closed chain of gear wheels, AB, Fig. 9. If the gears are allowed to slip at any point, *s*, the gear *f* being held stationary and the gear *e* turned in the direction of the arrow, then the chain of gears will be distorted, as shown in Fig. 10. Conversely, a chain of geared wheels, which by elastic action tend to stand in a row,* will be relieved from such a zig-zag distortion, as shown in Fig. 10 by permitting the gears to slip anywhere along the chain and the potential energy stored in the distorted chain will be geared towards the place where slipping takes place.

Let A and B, Fig. 11, be two metal plates and let each dotted line represent a closed chain of ether cells, like Fig. 9. An electric current forced through the wire means the forced slipping of ether cells all along the wire and each chain of the cells, initially like Fig. 9, becomes distorted like Fig. 10.

*The chains of positive and negative ether cells are thought of as standing in zigzag rows when undistorted, as shown by the horizontal rows in Figs. 2 and 3. Hereafter the chains of cells are to be thought of as straight (or uniformly curved) when free from distortion, in order that the diagrams may be simpler.

Throughout the region between A and B the positive ether cells receive an upward displacement and the negative cells receive a downward displacement, that is, this region becomes an electric field and the plates A and B become oppositely charged.

If the charged plates are now connected by a wire, as shown in Fig. 11, each closed chain of geared cells is cut by the wire, slipping begins all along the wire and the energy of each distorted chain of cells is transmitted along the chain, flowing into the wire as indicated by the arrows in the figure.

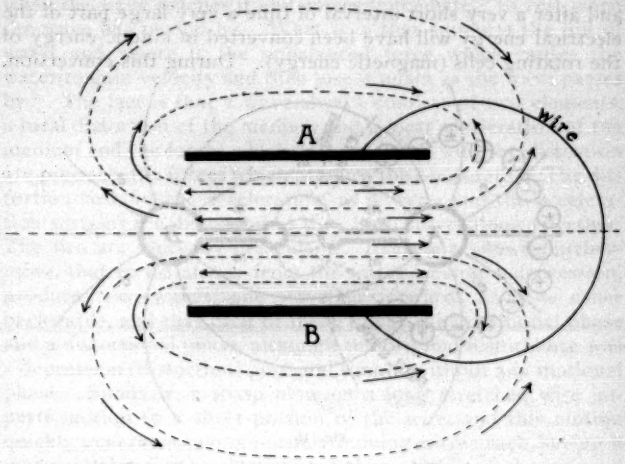


Fig. 11.

An electric spark is a line of slip produced by the breaking down of the mechanism which sustains the electric stress, and the electric energy flows in upon a spark as it does upon a wire carrying current.

The Electric Oscillator.—Let AB, Fig. 12, be the balls of the oscilator upon which electric charge has been collecting. Consider a chain of cells which, when undistorted, lies along a dotted line, which is everywhere perpendicular to the lines of force of the electric field. When A is positively charged, this chain is distorted as shown(in part), but since it is a closed chain,

this distortion is fixed. When a spark occurs at the gap, a line of slip is established across this chain, and the distortion disappears as above explained.

If the slip takes place with great friction (high electrical resistance in the gap), the cells at the spark begin turning slowly, and the entire energy of the electric field is geared into the gap and changed to heat. If the slip is almost frictionless (low electrical resistance), the electrical energy is used mostly in overcoming the inertia of the cells as they are set rotating, and after a very short interval of time a very large part of the electrical energy will have been converted in kinetic energy of the rotating cells (magnetic energy). During this conversion,

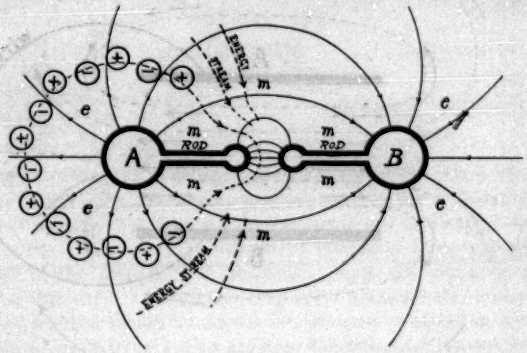


Fig. 12.

energy, streaming along the dotted lines, largely disappears from the regions *ee*, and is distributed mainly in the region *mm*. When the chain of cells has been freed from distortion, the rotatory motion of the cells between A and B will have reached a maximum, and on account of their momenta the cells will continue turning and produce a distortion of the chain in a reversed sense. At the same time the energy will, to a large extent, stream back from the region *mm* to the region *ee*, the ball A will be negatively charged, and the ball B will be positively charged. The reversed distortion of the chain of cells is then relieved by a reversed slip (a reversed current in the rods and gap), and so on.

These oscillatory changes take place so rapidly that the portions of the distorted ether which are remote from AB do not follow the changes promptly. This gives rise to electrical waves.

The Electromagnetic Wave.—Before describing the electromagnetic wave, it will be instructive to consider a common property of all wave motion. Take, for example, a wave traveling over the surface of water. This wave consists of a moving hill of water, and a given particle of water is set in motion when the wave reaches it and comes immediately to rest when the wave has passed by. What is it that supports the hill of water and where is the unbalanced force which causes the water to gain velocity and then lose it again as the wave passes by? The fact is that a wave always consists of two elements, a local distortion of the medium and a local acceleration of the medium and the forces which are associated with the distortion are precisely the forces which produce the acceleration. The distortion sustains the acceleration, as it were, and the acceleration sustains the distortion as they both travel along together. The two are mutually dependent. Everyone knows, furthermore, that to lift an oar from the water leaving a depression, produces two waves, one traveling forwards and the other backwards, and that each of these waves has a motional phase and a distortional phase, although the original disturbance was a depression (distortion) pure and simple, without any motional phase. Similarly, a sharp blow on a long stretched wire imparts motion to a short portion of the wire, and this motion quickly generates two oppositely moving waves each having a motional phase and a distortional phase, although the original disturbance consisted of motion only.

An electromagnetic wave also consists of a state of distortion and a state of motion traveling along together and mutually sustaining each other. The distortion is electric field and the motion is magnetic field. A layer of electric field unsustained breaks up into two electromagnetic waves just as an unsustained bend in a stretched wire breaks up into two waves, and a layer of magnetic field unsustained breaks up into two oppositely-moving electromagnetic waves just as a local state of motion of a wire produced by a hammer blow breaks up into two waves.

Some detailed ideas of the constitution of an electromagnetic wave may be obtained with the help of Fig. 13, in which the fine arrow lines represent the lines of force of a layer of electric field and the fine dots represents the lines of force of a layer of magnetic field directed towards the reader. This layer of electric and magnetic field moves to the right and constitutes an electromagnetic wave. The mutual sustaining action of the electric and magnetic field is explained in terms of Maxwell's cellular ether theory as follows: The two wires should be thought of as two broad metal ribbons for the sake of simplicity and they bound the electric wave very much as a speaking tube

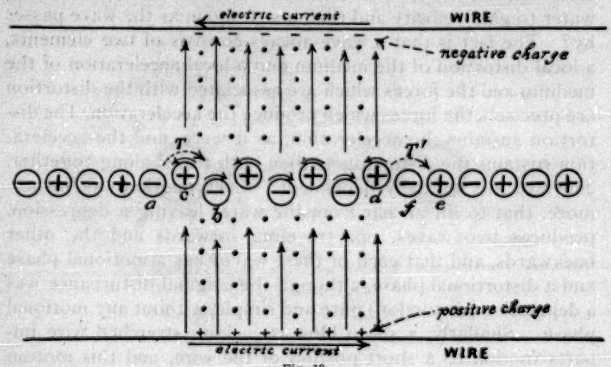


Fig. 13.

bounds a sound wave which passes through it. Midway between the two wires which bound the wave a simple chain of ether cells is indcated in Fig. 13. The part of this chain which lies within the wave is distorted and this distortion represents the electric field. Furthermore, those cells which lie within the wave are rotating as indicated by the small curved arrows, and this rotation represents the magnetic field.

Throughout the middle portions of the wave each rotating cell is acted upon by equal and opposite torques by the adjacent cells ahead of it and behind it, as explained in connection with Fig. 4. Therefore all the cells in the middle portion of the wave rotate at unchanging speed. The cell *d* however, exerts

an unbalanced torque upon cell *f* as indicated by a dotted arrow T^1 and this torque quickly sets the cell *f* rotating, while the cell *b* exerts an unbalanced torque *T* upon the cell *c* which quickly stops the rotation of the cell *c*. Thus the state of motion of the cells between *c* and *f* travels to the right. Likewise the state of distortion travels to the right inasmuch as this state of distortion is inseparably associated with the torque actions just referred to.

The terminating of the electric lines of force at the wires which bound the wave constitutes electric charges, positive on one wire and negative on the other, and electric currents flow along the two wires within the space occupied by the wave. This electric current flows in one direction in one wire and in the opposite direction in the other wire. The necessity for this current flow is involved in the bounding of the wave by the metal wires or ribbons, inasmuch as the rotation of the ether cells on one side of the ribbon with stationary ether cells on the other side, requires slipping of adjacent cells in the material of the ribbon.

The mutual dependence of the moving electric and magnetic fields which together constitute an electromagnetic wave may be expressed in terms more or less familiar. Before attempting this, however, it may be well to state that the fundamental relation between force and acceleration in mechanics *is in electromagnetic theory the same thing as the relation between electromotive force and changing magnetic flux*. A magnetic field of intensity *H* moving sidewise at a velocity *v* produces electromotive force according to the equation $E = l\,H\,v$, or in general $E = l\,\mu\,H\,v$ or since E/l is electric field intensity *e* we may write

$$e = \mu\,H\,v \quad (1)$$

in which μ is the magnetic permeability of the medium.

Now, another fact, not generally known among practicing electricians, is that an electric field of intensity *e* moving sidewise at velocity *v* produces magnetomotive force F according to the equation $F = l\,e\,v$, or in general $F = l\,k\,e\,v$, or, since F/l is magnetic field intensity H, we may write,

$$H = k\,e\,v. \quad (2)$$

in which *k* is the inductivity of the dielectric medium.

The condition which must be satisfied in order that the whole

of H may be due to the sidewise motion of e and at the same time the whole of e due to the sidewise motion of H, that is, that H and e may sustain each other completely, is that equations (1) and (2) be simultaneous equations. Treating equations (1) and (2) therefore as simultaneous equations we have :

$$v = \frac{1}{\sqrt{\mu k}} \quad (3)$$

and

$$\tfrac{1}{2} \mu H^2 = \tfrac{1}{2} k e^2 \quad (4)$$

Equation (3) gives the velocity at which H and e must move sidewise so as to be mutually dependent on each other. This is, of course, the velocity of an electromagnetic wave. Equation (4) expresses the fact in a so-called pure electromagnetic wave the magnetic energy is always and everywhere equal to the electric energy.

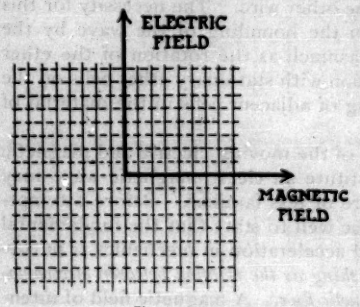


Fig. 14.

Fig. 14 represents a front view of a plane electromagnetic wave approaching the reader. The full lines represent electric lines of force and the dotted lines represent magnetic lines of force.

Wave Distortion.—The distortion of an electromagnetic wave, which is so troublesome in telephonic transmission, is due to the resistance of the wires or ribbons which bound the waves and to the conductivity of the insulating medium between the wires, and a clear understanding of electromagnetic wave distortion depends upon clear ideas of these effects of line resistance and line leakage.

One may see from Fig. 13 that the frictional resistance of the slipping ether cells in the material of the wires (the mechanical analogue of line resistance) causes the angular velocity of the ether cells (the mechanical analogue of magnetic field) to decrease continually. In fact the effect of line resistence is to cause the magnetic field H in an advancing electromagnetic

wave to decrease as the wave moves along, while the electric field in an advancing wave is not directly affected by line resistance.

On the other hand, if the structure of the medium in the region occupied by the advancing wave gives way continuously to the ether stress which constitutes the electric field, this ether stress will decrease steadily as the wave advances just as a state of stress in a stretched molasses-candy rope decreases steadily with time. This steady giving way of the ether under stress is the mechanical conception of the conductivity of the insulating medium between the wires, that is of line leakage, and in fact the conductivity of the insulating medium between the wires of a transmission line causes the electric field to die away as the wave moves along, while the magnetic field in an advancing wave is not directly affected by line leakage.

The distortion of an electromagnetic wave pulse as it travels along a transmission line is due wholly to the fact that line resistance reduces magnetic field only and that line leakage reduces electric field only, and a detailed description of wave distortion depends upon a clear understanding of an impure wave, as it is called, that is, a wave in which either the magnetic field has been reduced below the value which is necessary to sustain the electric field or in which the electric field has been reduced below the value which is necessary to sustain the magnetic field.

It has already been pointed out how a local bend in a stretched string which is unsustained by local acceleration breaks up into two oppositely moving pure waves and how a local movement of a stretched string due to a hammer blow breaks up into two oppositely moving pure waves. From this it is not difficult to see that if a wave, originally pure, were to travel along a string which is strung through a viscous liquid, the viscosity of the liquid would cause the motion to die away as the waves travel along but would not directly affect the distortion of the string, and therefore, at each point on the string, that part of the distortion which is sustained by what remains of the motion, travels onward as a pure wave, while that part of the distortion which is not sustained, the excess of distortion as it were, breaks up into two oppositely moving pure waves, one of which merges with what Heaviside calls the head of the

wave, and the other moves backwards and generates what Heaviside calls the tail of the wave.

Fig. 15 shows in an exaggerated way, an electromagnetic wave in which the magnetic field M has been reduced by line resistance, while the electric field E has not been reduced, and

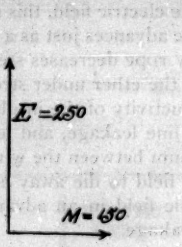


Fig. 15.

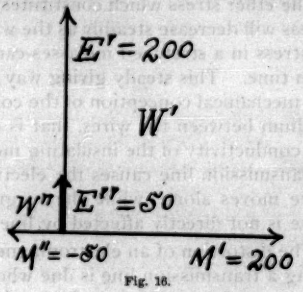


Fig. 16.

Fig. 16 shows the two pure waves W′ (which consists of E′ = 200 and M′ = 200) and W″ (which consists of E″ = 50 and M′ = — 50) into which this so-called impure wave resolves itself. The wave W′ continues to move forward and the wave W″ moves backwards.

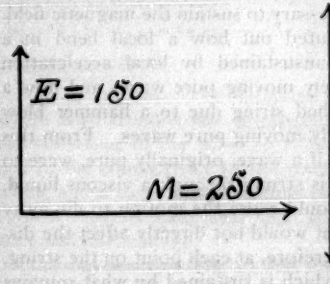


Fig. 17.

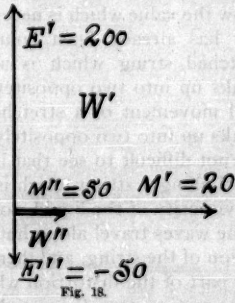


Fig. 18.

Similarly Fig. 17 shows an electromagnetic wave in which the electric field E has been reduced by line leakage, and Fig. 18 shows the two pure waves W′ and W″ into which this impure wave resolves itself.

Before describing the actual process of wave distortion, it is necessary to adopt a scheme for representing an electromagnetic wave pulse graphically. Such a representation is indi-

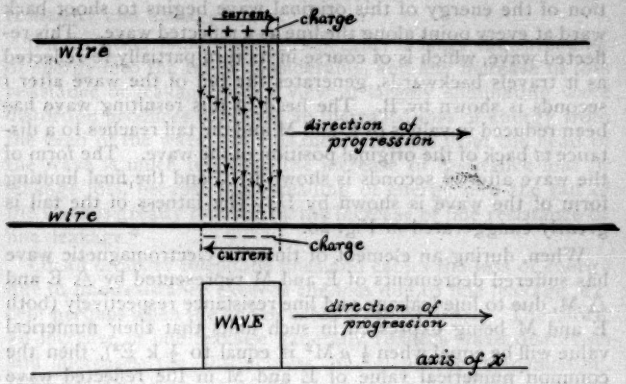


Fig. 19.

cated in Fig. 19. The rectangular curve marked "*wave*" in the lower part of this figure represents the pure wave pulse which is shown directly above it.

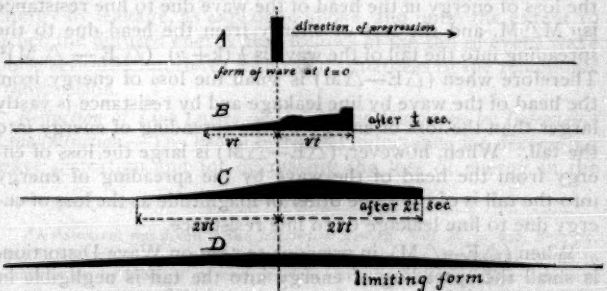


Fig. 20.

The black rectangle A, Fig. 20, represents a pure electromagnetic wave which at a given instant is supposed to be called into existence out on an indefinitely long pair of wires. As this

wave proceeds its magnetic field is decreased by line resistance (or its electric field is decreased by line leakage) and the wave becomes impure. The result is, as before explained, that a portion of the energy of this original wave begins to shoot back ward at every point along the line as a reflected wave. This reflected wave, which is of course in its turn partially re-reflected as it travels backwards, generates the tail of the wave after t seconds is shown by B. The head of this resulting wave has been reduced in values of E and M and the tail reaches to a distance vt back of the original position of the wave. The form of the wave after $2t$ seconds is shown by C and the final limiting form of the wave is shown by D. The fatness of the tail is greatly exaggerated in Fig. 20.

When, during an element of time, an electromagnetic wave has suffered decrements of E and M represented by $\triangle$ E and $\triangle$ M, due to line leakage and line resistance respectively (both E and M being expressed in such units that their numerical value will be equal when $\frac{1}{2}\ \mu\ M^2$ is equal to $\frac{1}{2}$ k E^2), then the common numerical value of E and M in the reflected wave which shoots out into the tail is $\frac{1}{2}$ ($\triangle$E—$\triangle$M) and the residual numerical value common to both E and M in the head of the wave is E — $\frac{1}{2}$ ($\triangle$E—$\triangle$M) or M — $\frac{1}{2}$ ($\triangle$E—$\triangle$M). The loss of energy in the head of the wave due to line leakage is k E$\triangle$E, the loss of energy in the head of the wave due to line resistance is μ M$\triangle$M, and the loss of energy from the head due to the spreading into the tail of the wave is $\frac{1}{8}$ (k+μ) ($\triangle$ E — $\triangle$ M)^2. Therefore when ($\triangle$E—$\triangle$M) is small the loss of energy from the head of the wave by line leakage and by resistance is vastly larger than the loss of energy by the spreading of energy into the tail. When, however, ($\triangle$E—$\triangle$M) is large the loss of energy from the head of the wave by the spreading of energy into the tail is of the same order of magnitude as the loss of energy due to line leakage or to line resistance.

When ($\triangle$E—$\triangle$M), in previous section on Wave Distortion, is small the spreading of energy into the tail is negligible in comparison with resistance loss and leakage loss, so that when ($\triangle$E—$\triangle$M) is small any increase of line resistance or leakage with a view of still further eliminating wave distortion produces an increased loss of energy from the head of the wave, which

is nearly equal to the increase of resistance loss or leakage loss of energy because when ($\triangle$E—$\triangle$M) is small the loss of energy from the head of the wave is sensibly equal to the sum of the resistance and leakage losses.

On the other hand when ($\triangle$E—$\triangle$M) is large the spreading of energy into the tail is considerable, and any increase of loss resistance or leakage with a view of largely eliminating wave distortion produces of course an increased loss of energy from the head of the wave, but this increased loss from the head of the wave is much less than the increase of resistance loss or leakage loss, because the spreading of energy into the tail of the wave is greatly reduced by the increase of line resistance or line leakage.*

On all ordinary telephone lines and cables the loss of energy due to line resistance exceeds the loss due to line leakage, except perhaps when the line or cable is out of order. Therefore, an increase of line leakage generally reduces wave distortion and increases the distinctness of telephonic transmission. Whether this increase of line leakage is justifiable depends largely upon whether it is constant and independent of the weather, upon the degree of wave distortion, for if the wave distortion is excessive the reduction of useful energy in the head of the wave is by no means equal to the increased loss of energy by leakage, as explained above, and upon the extent to which the diffused energy that follows in the tail of every wave pulse seriously interferes with the distinctness of the telephonic transmission.

Reduction of Line Losses and of Wave Distortion by Increasing Line Induction.—The use of increased inductance for decreasing wave distortion and for decreasing the loss of energy in the

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*A statement was given in the *Electrical Review*, Vol. 46, p. 242, Feb. 11, 1905, in illustration of this tendency to actually conserve the useful energy in a wave pulse by increase of line resistance or line leakage. This statement was, that an increase of the leakage of a perfectly insulated line so as to make the leakage loss equal to the resistance loss results in an increased energy loss from the head of the wave in the ratio of $1\frac{1}{2}$ to 2. This statement is faulty inasmuch as for some inexcusable reason it was based upon the aberrant idea that the energy of a wave is proportional to E (or M) instead of to E^2 (or M^2) as everyone knows.

head of a wave pulse while traveling over a given line may be shown in a very simple and elementary way as follows:

In the first place equations (3) and (4) may be written

$$v = \frac{1}{\sqrt{L\,C}} \qquad (5)$$

$$\tfrac{1}{2}\,L\,i^2 = \tfrac{1}{2}\,CE^2 \qquad (6)$$

in which L is the inductance of the transmission line per unit length, C is its capacity per unit length, i is the current flowing outward in one line and backward in the other at a given point on the line, and E is the electromotive force between the lines at the given point. The derivation of (5) and (6) from (3) and (4) need not be considered, although it is simple.

Let us consider a special case for the sake of clearness. Suppose a battery of electromotive force E is suddenly connected to the sending end of the line and a moment later disconncted. A rectangular wave of length l would be started along the line. This wave contains a certain amount of energy, a certain portion of which is dissipated or left dangling along the line, and the remainder arrives in the head of the wave at the receiving station. Suppose now that L is quadrupled, C and E being kept unchanged for the sake of comparison. Then from equations (5) and (6) v would be halved and i would be halved. If the sending battery is now connected to the line for the same length of time as before, a rectangular wave of length $\frac{1}{2}\,l$ will be started along the line, inasmuch as v is halved. Now, current flows in the line wires only where the wires bound the wave, that is in length l of the double line in the first case and in length $\frac{1}{2}\,l$ of the double line in the second case. Furthermore, the time required for the wave to reach the distant end of the line is twice as great in the second case. Therefore $R\,i^2\,t$, or the total energy dissipated in the wires from the head of the wave, is one-quarter as great in the second case as in the first, since R is halved, i^2 is quartered, and t is doubled. But the total energy is the wave is half as great in the second case as in the first case, since l is halved and the energy per unit length is unchanged, viz.: $(\frac{1}{2}\,L\,i^2 + \frac{1}{2}\,CE^2)$. Therefore the percentage loss of energy from the head of the wave is halved by quadrupling the line inductance. In this ex-

ample resistance loss alone is considered inasmuch as leakage loss is constant under the assumed conditions. The effect of increasing the inductance of a telephone line, loading the line as it is called, is the same as decreasing its resistance insofar as line losses and wave distortion are concerned, provided we are concerned with pure wave transmission. It must be remembered indeed that equations (4) and (6) apply to pure waves only. As applied to pure waves these equations indicate that for a given line there is a fixed relation between voltage and current. Neither can be changed without changing the other unless the line constants are changed. The inapplicability of equations (4) and (6) in their simple form to an alternating current transmission line is at once evident when we consider that there is no fixed relation between current and voltage on such a line. Alternating current transmission is not pure wave transmission.

The extension of this discussion to waves produced by steadily maintained periodic electromotive forces is beyond the scope of the present lecture, and the limitation of the discussion to the wave pulse is deemed advisable for two reasons,

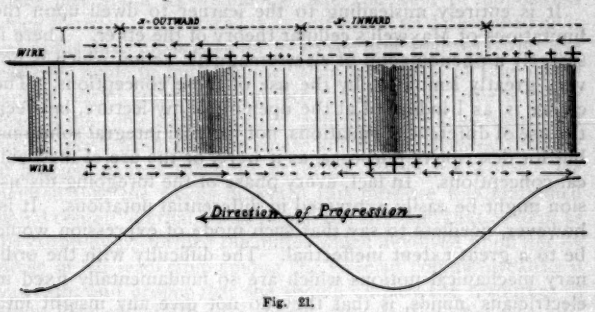

Fig. 21.

+ and — signs represent electric charge on the wires.
The short arrows represent electric current.
Dots represent magnetic lines of force.
Fine lines represent electric lines of force.

E.m.f. between wires at point x equals $E \sin\left(\frac{x}{\gamma}+\frac{t}{\tau}\right)$

Current in one wire at point x equals $I \sin\left(\frac{x}{\gamma}+\frac{t}{\tau}\right)$

viz.: (a) the theory of wave distortion may be completely covered by a consideration of the behavior of a wave pulse, and (b) the physics of wave motion in a medium involving reactions, which in optics gives rise to absorption and dispersion and in electric transmission gives rise to distortion and attenuation, is vastly simpler for the wave pulse than for the wave train. The wave train represents a steady state of a system under the action of a periodic force which has been kept up long enough for the system to settle down to a steady state of motion, and *this steady state depends upon what is taking place at every point in the system*, whereas the wave pulse, the head at any rate, has to do only with what takes place at one single point in the system. The physical nature of a simple electromagnetic wave train is shown in Fig. 21. The curved line at the bottom of the figure is a representation of the wave train.

The reader should keep in mind the fact that all of the discussion as outlined above is based first upon the determination of electromotive force, and current relations on the assumption that line resistance and line leakake are zero, after which line resistance and line leakage are considered as disturbing effects.

It is entirely misleading to the learner to dwell upon the limitations of Maxwell's cellular theory of the ether. There is scarcely a phenomenon of electromagnetic action which is not very greatly simplified by the use of these conceptions. The choice is, as I indicated at the opening of my lecture, between the use of differential equations, not for final integral solutions, but for descriptive purposes, as it were, or the use of mechanical conceptions. In fact, every phase of the foregoing discussion might be easily expressed in differential notations. It is, however, needless to say that such mode of expression would be to a great extent ineffectual. The difficulty with the ordinary mechanical notions which are so fundamentally fixed in electricians' minds, is that they do not give any insight into electromagnetic action, and the difficulty with the cellular theory, aside from the one mentioned by Poynting, is that it may perhaps never give any insight into the phenomena of moving electrons. My advice to the younger readers is to swallow Maxwell's cellular theory and digest it, and do not turn away from it in disgust because some one says, truly, that is does not contain the secret of the universe.

THE FRANKLIN INSTITUTE.

Civic Beauty and Civic Duty.*

By Leslie W. Miller,*

Principal of the School of Industrial Art of the Pennsylvania Museum.

[The author presents in fascinating form the argument for the beautification of our cities from the ethical and aesthetic viewpoint.—The Editor.]

The answer that Pericles made to his critics and opponents when he was blamed for spending so much money in beautifying Athens has been repeated almost in his very words by every public-spirited ruler who has been similarly criticised from that day to this, and it is quite as true to-day as it was twenty-four centuries ago. Unfortunately, too, the necessity for making it arises just about as frequently, and the kind of opposition which Pericles encountered is as active and as determined as it was in his day. It is easy for us to see now that no better use was ever made of public money than was made of that which came in such a golden stream into the coffers of Athens as the head of the Ionic Confederation, and which Pericles spent with such a lavish hand with the single and openly-avowed purpose of making Athens the most beautiful city in the world. He claimed that the works in which this purpose was embodied would confer "eternal honor" upon the city, and that as long as she faithfully performed the duties which devolved upon her by virtue of her leadership among the Grecian commonwealths it was right and proper that she should employ the resources of her position in works that should fittingly signalize and adequately express the leadership which she had so honestly earned and which was so cheerfully accorded her.

It is worth while to pause occasionally in our headlong pursuit of the material and utilitarian aims by which the ideals of

*A lecture delivered before the Franklin Institute, in Association Hall, Friday, January 13, 1905.

to-day are so largely dominated, and to consider what Pericles had in mind and, consequently what it means to care, and to care a great deal, for the mere beauty of things, especially public things, and to note and estimate the part which this regard has played, and must always play, in the life not only of individuals, but of entire communities.

We know now that Pericles was right. Athens has contributed in many ways to the kind of attainment which the world has agreed to hold in the highest honor, but nothing that she ever did has brought her more honor, or done more to assure her the proud position among the cities of the earth which for more than twenty centuries has been accorded her than the pure beauty of the things she built and made.

> "Earth proudly wears the Parthenon
> As the best gem upon her zone,"

and she not only wears this beauty with a kind of pride that is perhaps the only one that is altogether justifiable, she has learned to accept it as the proper, and to a certain extent necessary, expression of most desirable qualities, so that it is impossible to approve the expression without appreciating the quality. All our systems of aesthetics have this in common, that whatever else it is, or is not, beauty is mainly an outward and sensible manifestation of inward perfectness. And while the outward expression may not always argue a corresponding inward perfection, it is at least a reminder of it and a stimulus of effort toward it. We are slowly learning that instead of being an exceptional and exclusive thing, the passion for beauty is among the most fundamental and universal of human instincts, and that the cultivation and direction of this instinct is of the very first importance to the life and health not only of individuals but of communities, of cities and states and nations.

The joy and content of the workman and the devotion and loyalty of the citizen are inseparable from the kind of pride which noble achievement inspires and what is beauty but the simplest and most direct form in which such achievement expresses itself? There can hardly be a more mistaken public economy than that which leads through palpable neglect to inevitable shame. Real leaders have always understood this and

the example of Pericles at Athens is exceptional only in its brilliance. Augustus is remembered not because his armies were successful at Phillippi and at Actium, but because his boast that he found Rome brick and left it marble voiced a sentiment that commands admiring approval wherever society is organized and cities are built. Dante's heart was broken by his exile from Florence, but the burden of the plaint which he made was not so much regret for the loss of his home and family as grief for "the fairest and most renowned daughter of Rome," as he called the city of his birth, whose life he could no longer share. And so of any other city, ancient or modern, to which its inhabitants are genuinely attached; is it not its beauty that they think, and speak, of first? Did anyone ever know a citizen of Venice or of Paris, for example, to emigrate, except under compulsion, or to give any better reason for preferring to stay where he was than the pure beauty of the place itself?

We Americans have something to learn from the experience and example of older countries, and some sins, mainly of omission, to repent of and expiate, but there was never a better sign anywhere than the awakening to the sense of our shortcomings which animates so much present-day discussion, and the energy that is devoting itself, all around us, to the development of civic beauty as at once the expression and the inspiration of civic spirit.

It is encouraging, too, to remember, in spite of so much prevalent misconception on this point, how popular and democratic the most conspicuous movements in the direction of civic embellishment have always been. From Pericles' time to our own, the most beautiful cities have either been free and independent republics or municipalities, or else they were communities whose taste, rather than that of the nominal ruler, determined the treatment which the city received. Probably few monarchs ever cared less either for art or for the people that Louis Napoleon, but he knew how important to his peace of mind it was that Paris should be pleased, and he knew how to please her. As a matter of fact it makes very little difference whether monarchs or burghers rule the cities in name. The cities themselves reflect and express, always and everywhere, only too true sometimes, the temper and the tastes of those whom they shelter.

It is delightful to find this popular responsibility accepted and the popular will expressed as frankly and unequivocally as it was stated in the decree by which the City Council of Florence authorized, in 1298, the reconstruction of the Cathedral "in a style of magnificance which neither the industry nor power of man can surpass, that it may harmonize with the opinion of many wise persons in this city and state, who think that this commune should not engage in any enterprise, unless its intention be to make the result correspond with that noblest sort of heart which is composed of the united will of many citizens," but ordinances of city councils do not often copy this admirable model very closely and the demand of the councillors of the modern city that the best art attainable shall be applied to the service of the public is sometimes, it is true, not so much stated as left to be inferred, but times have changes and councillors have changed with them.

All the great work of the Cathedral builders seems to have been done in much the same spirit as that which the Florentine burghers expressed so well. Probably without exception the splendid structures of the Gothic period are to be regarded as representing not so much the ascendency of the church as the pride of the town in its principal building. This is not the place to trace the reasons for the changes in both religious and civic ideals that have resulted in the decline of the cathedral-building fervor and the diversion into other channels of the energy that was once so largely monopolized by the church, but whether expressed in terms of ecclesiastical magnificence or stately structures of any other kind, the popular purpose and the civic pride which really good public art for the most part represents must not be forgotten.

Let us consider some of the things which share with the church the service which the civic spirit creates, and first the streets. The narrow paths which ran between the rows of huts which served as dwellings for the Greeks, and the dark and crooked alleys in which the cathedral builders lived would not be tolerated a moment in any modern city, but we must not only have streets, we must have open spaces, plazas, playgrounds and parks. It is all very recent, the thought of pleasure-grounds and breathing-places for the use of everybody (the public park, as we know it, hardly existed before 1850), but the

demand for them is very real now. And so of all appliances for transportation and education and justice and all manner of utilities on which the health, comfort and well-being of the inhabitants depend. They played a very small part in the thought of our immediate ancestors compared with the attention which they receive to-day. The duties which they represent are not to be evaded, the only question regarding them relates to the spirit in which they are to be accepted and administered. The great city accepts the duties promptly and treats them not as tasks but as opportunities, but the mean-spirited ones meet them grudgingly as things to be shirked and neglected wherever this is possible. Now, a certain dignity and beauty are inseparable from an adequate and satisfactory administration of these responsibilities. The lessons that are of most abiding value and the memories which are best worth preserving are precisely those which cannot do without the setting which art alone can supply. As the civic spirit develops it learns that the search and service of beauty which we call art is far enough from anything like luxury or indulgence, but that, on the contrary, it stands for, and is the chief reminder and inspirer of, all that is serious and elevated in the life of the community.

REINFORCED concrete is the coming material in modern construction. According to some authorities; it is one of the monumental blunders of this mechanical age that the arches of the New York subway should be made of steel rather than of reinforced concrete.

CHEMICALLY pure iron, produced by electrolysis, has recently been made by Prof. C. F. Burgess, of the University of Wisconsin. The metal is said to be free from all foreign contamination, with the exception of a little hydrogen.

THE composition of the Welsbach mantle has much to do with the effective temperatures in and about the burning zone of gas. The maximum, according to V. Lewes, is reached with 99.9 per cent. thorium oxide, and 0.1 per cent. cerium oxide.

Correspondence.

Fuel Supplies of the Far East and the Possible Consequences to be Anticipated from their Development.

To the Editor:

A note in the Mémoires et *Compte Rendu des Travaux de la Société des Ingéniers Civils de France* (March, 1904), regarding the naphtha in the Extreme-Orient, has much interest in the present conditions of the Russo-Japanese struggle for supremacy in that region. The note referred to, represents oriental Asia as one of the richest parts of the globe in mineral combustibles. The area in Europe of all the coal basins under exploitation is an aggregate in round numbers of about 23,000 square miles, an area equal to only that of the Russian Province of Kasan alone. The extent of the coal deposits in oriental Asia, although they have received up to the present time but little attention, may be considered as incalculable. In addition to these deposits, that country possesses subterranean lakes of naphtha which can become in the near future the base of most important industries. Naphtha is found nearly everywhere in China, in Manchuria, in the Ussuri, in Japan, and in the island of Saghalien, which island also possesses a very rich coal basin, besides its very considerable lakes of naphtha.

An engineer who has examined the coal basins and the petroleum deposits of Texas and of Pennsylvania, and who has also made an exploration of the sources of the naphtha in the island of Saghalien, declared on his return to Bakou, that what he had seen in the United States was as nothing in comparison with what existed in that island. According to a report made by the consular agent of the United States at Vladivostok, the sources of naphtha near the river Nooteva in Saghalien, surpass in all respects the sources of petroleum in Bakou. There are subterranean lakes of naphtha in Saghalien, of which the largest alone has an area of about 72,000 square yards.

Note by Translator. The marvellous development of wealth, prosperity, knowledge and power that constitute the present civilization of the world, rests upon, and is measured by, the conversion of the heat of mineral combustibles into physical work; and as fuel and power are convertible terms, and as the wonderful renaissance of Japan has shown that the Asiatics are in no respects inferior in imagination, intellect, ingenuity and personal prowess to Europeans and their descendents elsewhere, while their command of fuel and of population is vastly greater, the question arises whether in the not very distant future, that "star of empire which westward took its way" may not have reached its zenith and commenced its retrograde eastward march. The figure of Macauley's New Zealander standing on the ruins of London Bridge, may not prove to be altogether a figure of rhetoric. Never ceasing change is the law of the Universe.

New York, June 18, 1905. B. F. ISHERWOOD.

Book Notices.

Die elektrochemische Industrie Deutschlands. Von P. Ferchland, Dr. Phil. Mit 4 Figuren und Tabellen im Text. 8vo, pp. viii×66. Hale a, S.: Verlag von Wilhelm Knapp. 1904. Price, 2.50 marks.)

This work constitutes Volume XII of the interesting and timely series of "Monographs on Applied Electrochemistry," which is being issued from the publisher's press. It gives a brief survey of the important electrochemical industries of Germany, where the development of this branch of applied science has been very great.

The work's author, after a brief historical introduction covering the origin and limitations of this branch of industry, and the sources of power production for electrochemical purposes, treats of the following special industries: Alkali and Chlorine (Bromine); Electrical Bleach; Hydrogen, Oxygen and Ozone; Calcium Carbide, Phosphorus; Sodium, Magnesium and Aluminum; Zinc; Copper, Nickel; Noble Metals; Other Inorganic Processes; Organic Electrochemistry; Power Consumption in the Production oi Electrochemical Materials. W.

Committee On Science and the Arts.

(Abstract of the proceedings of the stated meeting held Wednesday, June 7, 1905.)

Dr. Edward Goldsmith in the chair.

The following reports were adopted:

(No. 2216.) *The Nernst Lamp.* The Nernst Lamp Co., Pittsburgh, Pa.

Abstract: This report requires illustrations for proper understanding. It is accordingly reserved for publication in full.

The Committee's conclusions are as follows:

1st. The Nernst Lamp has come to stay and is filling an important place in electric lighting. It is economical in its use of energy; the color of the light which it supplies is attractive; it occupies a field midway between that occupied by the incandescent and the arc lamp.

2d. It is only applicable to A C circuits in which the voltage is quite steady. This limits its safe application to central station service in systems where the voltage is constantly under the supervision of experienced switchboard operators. The failure of the lamp under other conditions is not the fault of the lamp itself, but rather of the apparatus in every day use for distributing aternating current.

3d. Its commercial development in America in the hands of the Nernst Lamp Co. has made it possible to achieve the success in commercial operation which the lamp has met.

The report recommends the award of the John Scott Legacy Premium and Medal to the Nernst Lamp Co. for substantial improvements in the type of lamp devised by Dr. Walter Nernst. (*Sub-Committee*, Arthur J. Rowland, chairman; Thomas Spencer, Carl Hering, Geo. A. Hoadley.)

(No. 2313.) *The Semple Shell Torch.* John Bonner Semple, Pittsburgh, Pa.

Abstract: The object of this invention is to provide a means for the

rapid and accurate firing of projectiles at night, which has heretofore been a matter of extreme difficulty. This is practically overcome by the invention here considered. It is protected by letters-patent of the United States: Nos. 581,946, May 4, 1897, and 694,032, February 25, 1902, granted to applicant.

The distinctive feature of the shell torch is that it supplies the shell with a light which is ignited automatically a short distance beyond the gun and which burns during the entire flight of the shell, thereby rendering its trajectory clearly visible at night and vividly showing any error in the training of the gun. * * Another feature of the torch is that it will not be extinguished should it ricochet and pass under water.

The torch is attachable to any shell and consists of a brass cell filled with a pyrotechnic compound composed of ammonium nitrate, meal powder and magnesium powder, with just sufficient resin to hold the mixture together. The case is threaded to fit the opening of the shell intended for the base fuze or exploding device. The igniting apparatus is simple and is operated by a small quantity of gas from the propelling charge.

The great advantage of the shell-torch for night firing will be in siege operations, coast defense and the repelling of torpedo boats.

For further details, the reader is referred to the report, which will be published in full in the *Journal.*

The report proceeds to elaborate the various applications of the shell torch, and in conclusion makes the following recommendation, based upon the results of actual tests made by the military and naval authorities of the U. S. Government, viz: The John Scott Legacy Premium and Medal, to John Bonner Semple, of Pittsburgh, Pa., for his invention of a shell torch for firing projectiles at night. (*Sub-Committee,* Wm. O. Griggs, chairman; Frank Heath, Lt. Col. Ord. Dept. U. S. A., Comm'd't Frankford Arsenal; W. J. Williams, Chemist, Frankford Arsenal; Jos. H. Burroughs, late Major 1st Brig., N. G. Pa., Inspector of Rifle Practice.)

(No. 2338.) *Electrolytic Interrupter for Induction Coils.* Dr. A. Wehnelt, Charlottenburg, Germany.

Dr. Wehnelt's device is described as a contribution to science in the Elektrotechnische Zeitschrift, of January 26, 1889, to which reference is made for a suitable description. This report, also, will presently appear in full in the *Journal.*

The investigators conclude their report with the following recommendation: "In consideration of his work in the development of the electrolytic interrupter and its consequent adaptability to the practical application of the X-ray in surgical and other work, the award of the John Scott Legacy Premium and Medal is recommended." (*Sub-Committee,* Geo. A. Hoadley, chairman; Geo. F. Stradling, H. Clyde Snook.

(No. 2357.) *Photo-printing Machine.* L. F. Rondinella, Philadelphia.

The object of this invention is to product photographic prints in continuous form from tracings or other flexible transparencies of unusual length.

It is the subject of letters-patent of the U. S., No. 670,349, March 19, 1901, granted to the applicant.

The report will be published in full in the *Journal*.

The report finds that this inventor was the pioneer in this class of apparatus and concludes that "in view of the scientific accuracy and mechanical thoroughness and simplicity with which all the various requirements of the process of continuous photo-printing have been fulfilled in this machine," the inventor is entitled to the award of the John Scott Legacy Premium and Medal, the grant of which is accordingly recommended. (*Sub-Committee*, Louis E. Levy, chairman; Thos. P. Conard, H. R. Heyl.)

(No. 2360.) *Method of Producing Replicas of the Rowland Diffraction Gratings.* F. E. Ives, New York.

A full description of this method appears in the *Journal* for June, 1905, to which reference is made. The report in referring to the value of these replicas states that they show good definition and very little distortion, so that any part of the surface may be used with equal accuracy.

A photograph of the E b region of the solar spectrum made with one of these replicas in a Browning Student's Spectroscope shows with good definition every b group line that appears in the Angström and Kirchhoff maps, and more than fifty lines between E and b.

These replicas are low in price as compared with the cost of the original grating, and since they have the grating surface protected and are of a high grade of accuracy, they are well adapted for the use of students in the laboratory.

The investigators add that from tests made by their members, and with comparisons made with other forms of replicas, they are of the opinion that a valuable contribution has been made to apparatus for the study of light and its phenomena, and recommend the award of the John Scott Legacy Premium and Medal to the inventor. (*Sub-Committee*, George A. Hoadley, chairman; Louis E. Levy, George F. Stradling, Samuel Sartain.)

The following reports passed first reading:

(No. 2364.) *The Folmer & Schwing "Graflex" Camera.* Folmer & Schwing Mfg Co., Utica, N. Y.

(No. 2368.) *System of Flame Regulation.* Byron E. Eldred, New York.

(No. 2367.) *Drawing Pen.* Theodore Alteneder & Sons, Philadelphia.

(No. 2359.) *Alternating Current Motor.* Mitford C. Massie, Washington, D. C.

WM. H. WAHL,
Secretary pro tem.

Sections.

MECHANICAL AND ENGINEERING SECTION.—*Stated Meeting* held Thursday, May 25th. Mr. James Christie in the chair. Present, sixty-four members and visitors.

The evening was devoted to a continuation of the discussion from the previous meeting (Thursday, April 27) on "Internal Combustion Engines." The Chairman opened the discussion with some general considerations on the subject.

Mr. J. R. Bivins, representing the Westinghouse Machine Co., Pittsburgh, followed with some interesting remarks on the theory of the inter-

nal combustion engine. Mr. Bivins's remarks were illustrated with the aid of a number of lantern pictures.

Mr. Henry Hess, representing the Hess-Bright Manufacturing Co., Philadelphia, followed with remarks having especial reference to the use of ball-bearings to reduce journal friction.

Mr. Francis Head gave a description of the Mietz-Weiss oil engine.

A general discussion followed, which was participated in by Messrs. John C. Parker, E. Goldsmith, Henry R. Heyl and the Chairman.

Adjourned.

WM. H. WAHL,
Secretary pro tem.

Franklin Institute.

(Proceedings of the stated meeting, held Wednesday, June 21, 1905.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, Wednesday, June 21, 1905.

PRESIDENT JOHN BIRKINBINE in the chair.

Present, twenty-six members and visitors.

Additions to membership since last report, eight.

The paper of the evening was presented by Mr. George W. Fuller, of New York. It was entitled "Sewage Disposal from the Standpoint of Oysters and Other Shellfish, Especially With Reference to their Transmission of Typhoid Fever." The speaker pointed out that laboratory tests both here and in foreign countries had demonstrated the presence of various disease germs in shellfish, their life in the oyster, clam, etc., ranging from seven to twenty-one days, and said that while notable epidemics due to the eating of sewage-contaminated oysters are comparatively rare, there is no room for doubt that numerous sporadic cases have resulted from this cause. The investigations by the Royal Commission on Sewage Disposal of England, he said, indicate that about 10 per cent. of the total deaths from typhoid in London and Manchester are due to eating infected shellfish, but data on this point, in this country, have not been studied with sufficient care to give accurate conclusions.

The paper was discussed by Dr. George A. Loper, of New York; Dr. Henry Leffmann, of this city, and Kenneth Allen, engineer of the Water Supply of Atlantic City, all of whom agreed with the author of the paper that there should be a competent sanitary inspection of oyster beds in their relation to sewage contamination and that the sale or shipment of contaminated oysters should be prohibited by law.

The President expressed the thanks of the meeting to the speaker of the evening and to the participants in the discussion, and the meeting was adjourned.

WM. H. WAHL,
Secretary.